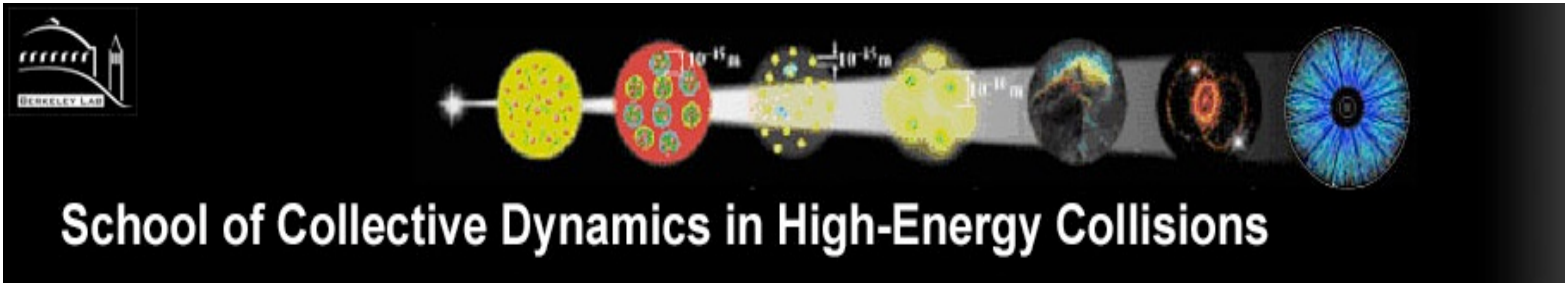


Search for Medium Modification of Vector Meson Properties at JLab

C. Djalali, R. Nasseripour (University of South Carolina)

D. P. Weygand (Jefferson Lab)

M. H. Wood (University of Massachusetts, Amherst)

and **CLAS Collaboration**

Berkeley, May 21 - 26, 200

UNIVERSITY OF SOUTH CAROLINA

Outline

- Physics Motivations
- Some key Experiments
- Jlab Hall B
  - CLAS
  - “g7” experiment
  - Lepton ID
  - Background studies
  - g7a results
- Summary and Conclusions

- Disclaimer: Not all experiments and models listed!

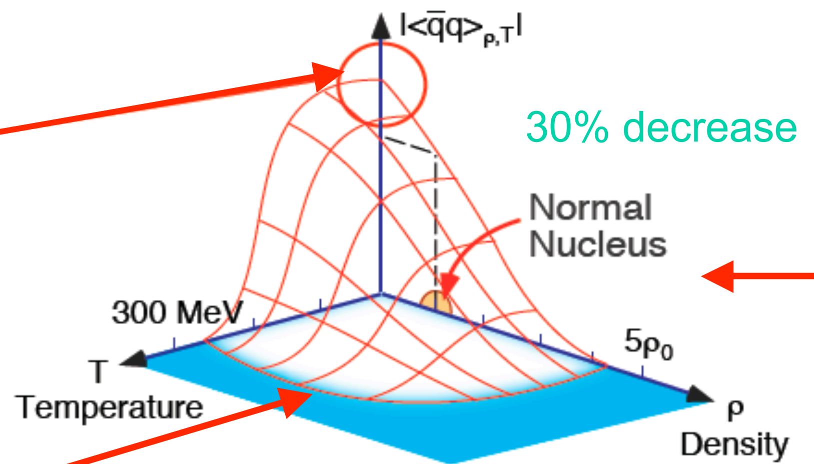
Physics Motivations

Hadronic properties depend on the chiral condensate $<0|q\bar{q}|0>$

$<0|q\bar{q}|0>$ Changes with ρ and T.

As $<0|q\bar{q}|0> \rightarrow 0$, Restoration of chiral symmetry.

Chiral symmetry is spontaneously broken,



Partial restoration of chiral symmetry

chiral symmetry restored

T. Hatsuda and T. Kunihiro, Phys. Rev. Lett. 55 (1985) 158.
W. Weise, Nucl. Phys. A443 (1993) 59c.

The quark condensate decreases with increasing the nuclear density and temperature (chiral symmetry restoration) *[see W. Weise lecture and references]*

Physics Motivations

Properties of vector mesons are predicted to change with ρ and T

Scale invariance in effective Lagrangian:

G.E. Brown and M Rho, ***Phys. Rev Lett. 66 (1991) 2720***

$$\frac{m_V^*}{m_V} = \frac{m_N^*}{m_N} = \frac{f_\pi^*}{f_\pi} \approx 0.8 \quad \text{At } \rho_0$$

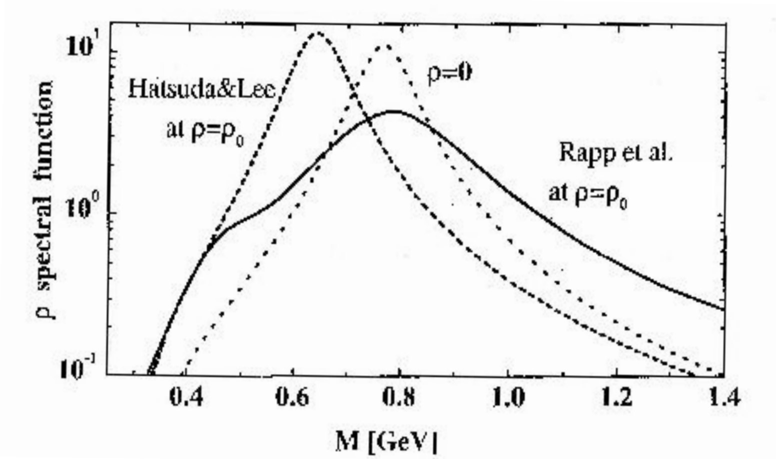
QCD sumrules:

T. Hatsuda and S. Lee ***Phys. Rev. C46 (1992) R34***

$$\frac{m_V^*}{m_V} = 1 - \alpha \frac{\rho_B}{\rho_0} \qquad \alpha \approx 0.16 \pm 0.06$$

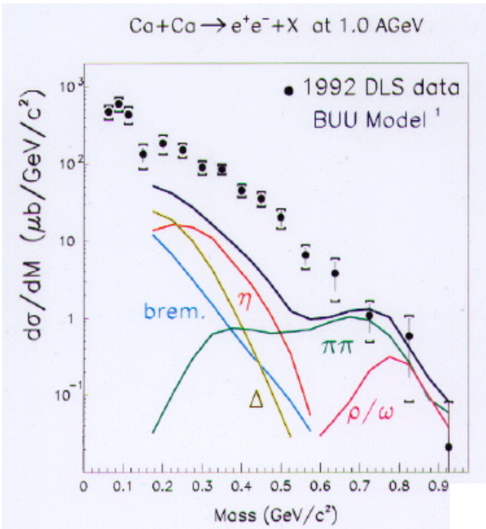
Many body effects:

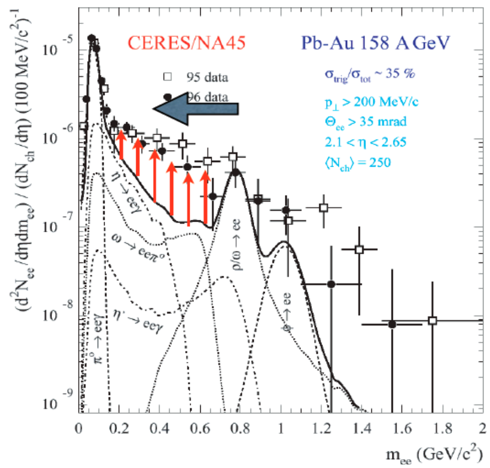
B Friman, H.J. Pirner,
Nucl Phys. A617 (1997) 496
R. Rapp, G. Chanfray, J Wambach,
Nucl Phys. A617 (1997) 472
R. Rapp, ***arXiv:nucl-th/0608022 (2006)***

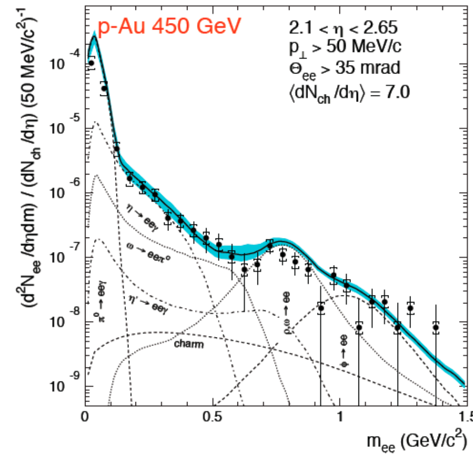


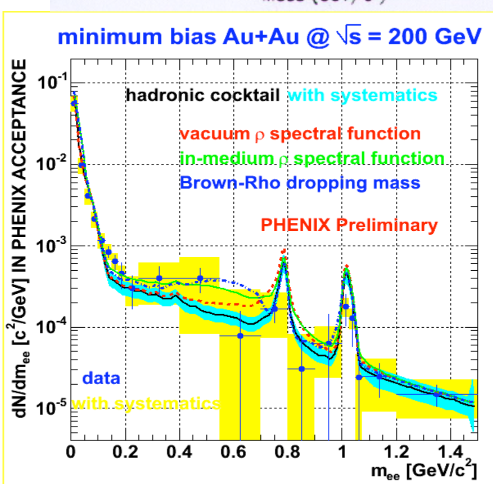
Are these modifications observed??

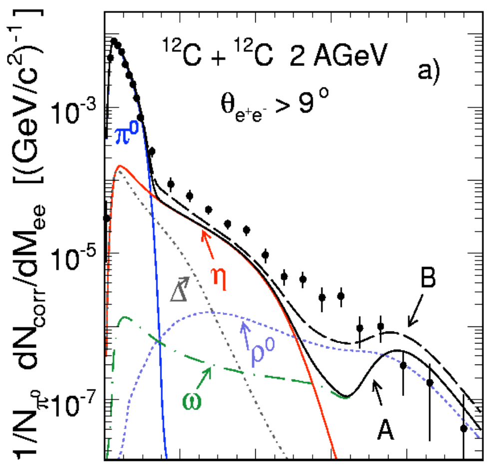
Some HI results (see other talks)

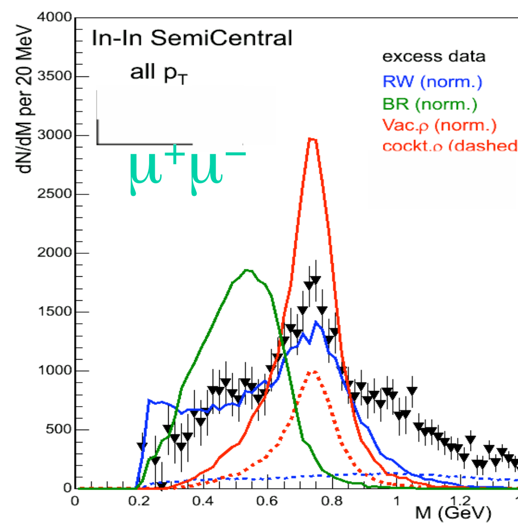








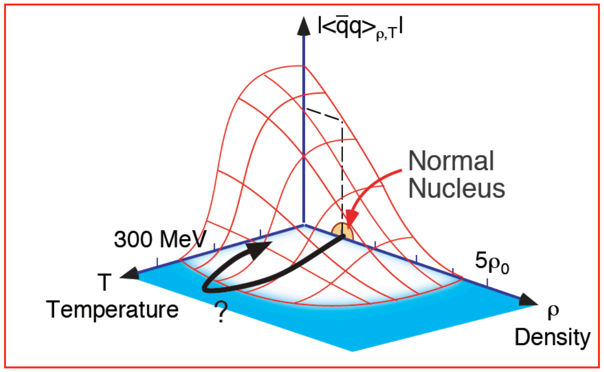


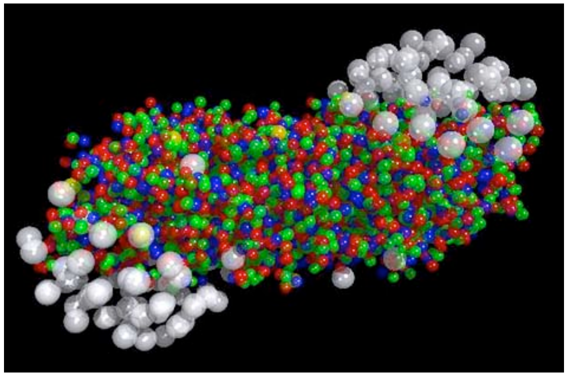


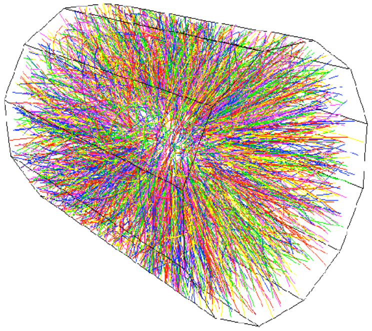
Clear excess of di-leptons observed. NA60: Γ↗ , no ΔM

Medium modification of vector meson properties seem to explain HI results HOWEVER

1) In A+A collisions, the results are integrated over a whole range of ρ and T; "it is hard to get easily to the elementary process"!
2) In A+A collisions, the interesting phase of matter is produced (if at all!) in the very early stages of the reaction, generally far from equilibrium, making it hard to directly compare to the theoretical models which all assume equilibrium.
3) In A+A collisions, many channels are involved



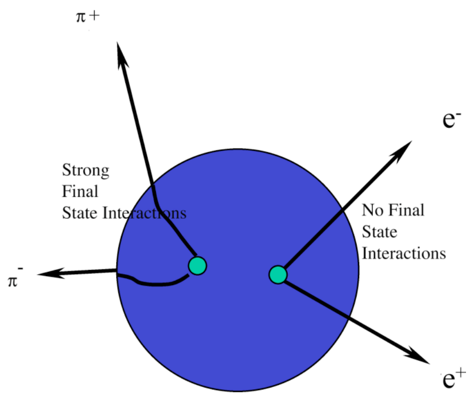


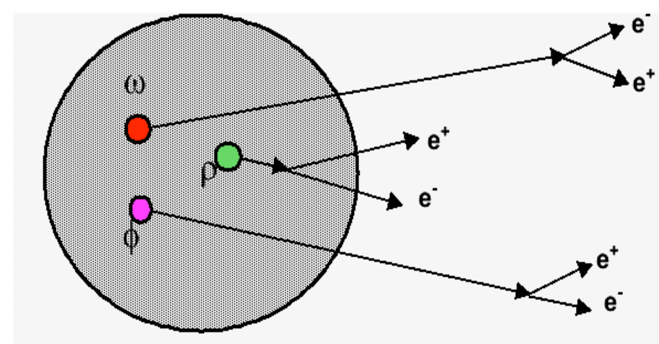


It is interesting to look for medium modification of vector meson properties in nuclei (at T=0 and $\rho \sim \rho_0$)

The predicted medium modifications are so large that even at normal nuclear density, they can be observed, so:

- Let's produce Vector mesons in nuclei.
- Do it with probes that leave the nucleus in almost an equilibrium state γ, π, p,..
- (probe) + A --> V X --> e^+e^- X





Decay inside

Vector mesons $J^P=1^-$	ρ:	M=768 MeV	Γ= 149 MeV	$c\tau \sim 1.3$ fm
	ω:	M=782 MeV	Γ = 8 MeV	$c\tau \sim 23.4$ fm
	ϕ:	M=1020 MeV	Γ = 4 MeV	$c\tau \sim 44.4$ fm

Need very low p

Present and planned "elementary reactions" (not exhaustive list):

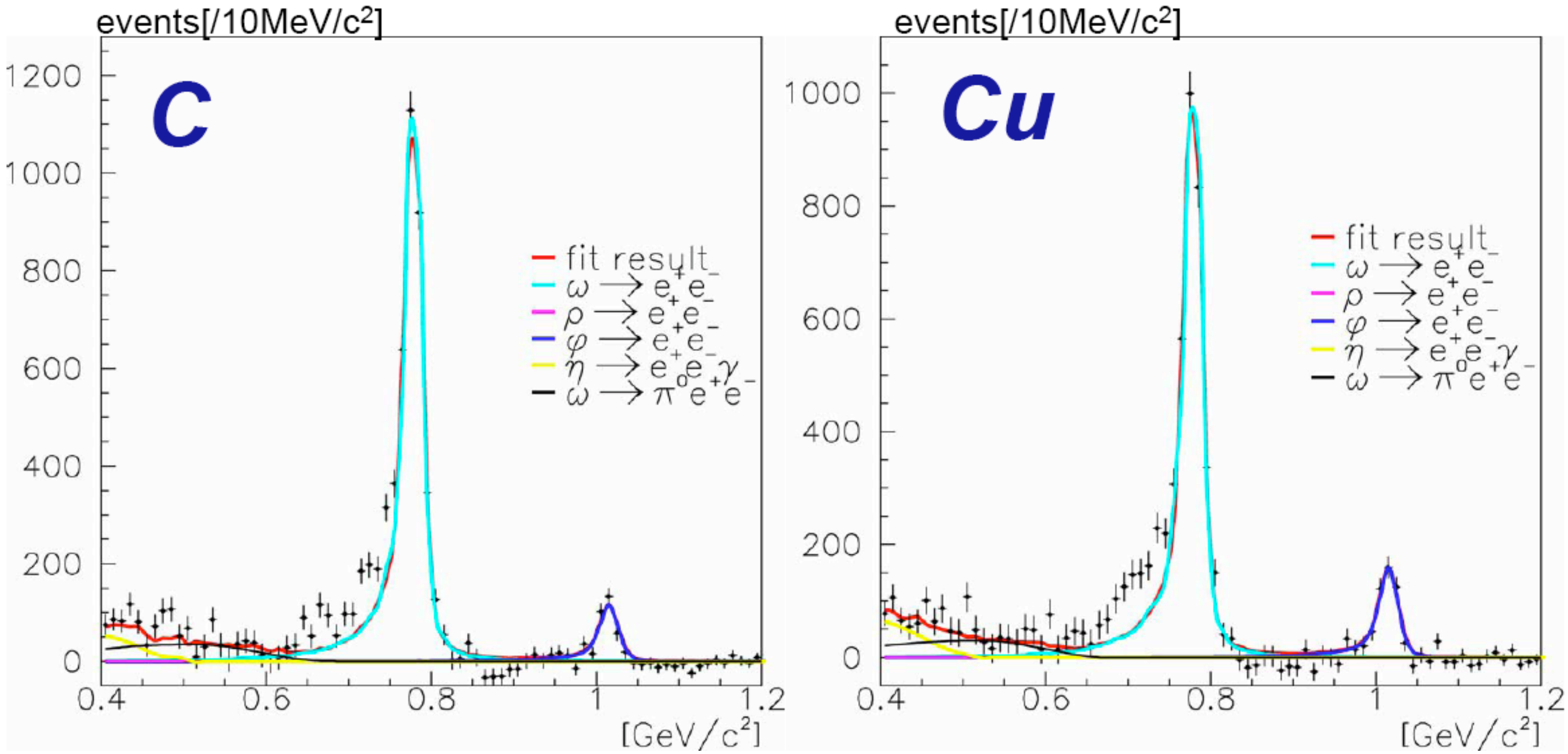
Experiment	***Reactions***	***Results***
TAGX	$\gamma + {}^3He \text{-->} \rho + X\ (\rho \text{->} \pi^+\pi^-)$	full BR, $\alpha \sim 0.06$
KEK	$p+A \text{->} \rho,\omega,\phi + X\ (\rho,\omega \text{->} e^+e^-)$	$\alpha = 0.092 \pm 0.002$
KEK	$p+A \text{->} \phi + X\ (\phi \text{->} e^+e^-)$	$\alpha \sim 0.04$
SPring-8	$\gamma + A \text{-->} \phi + A^*(\phi \text{-->} K^+K^-)$	no effect
TAPS	$\gamma + A \text{-->} \omega + X\ (\omega \text{-->} \pi^0\ \gamma)$	$\alpha \sim 0.13$
JLab-g7a	$\gamma + A \text{-->} (\rho,\omega,\phi) + A^*\ (VM \text{-->} e^+e^-)$	$\alpha = 0.02 \pm 0.02$
JPARC	$p+A \text{->} \rho,\omega,\phi + X\ (\rho,\omega,\phi \text{->} e^+e^-)$	proposal #16
HADES	$p+p,d \text{->} \rho,\omega,\phi + X\ (\rho,\omega,\phi \text{->} e^+e^-)$	(running)

-Only g7 with EM interaction in entrance and exit channels
-KEK cannot easily extract ρ
-TAGX, Spring8 and TAPS have hadronic FSI.

KEK-PS E325

p+A->ρ,ω,ϕ+X (ρ,ω,ϕ->e+e-)

M. Naruki et al, PRL 96 (2006) 092301



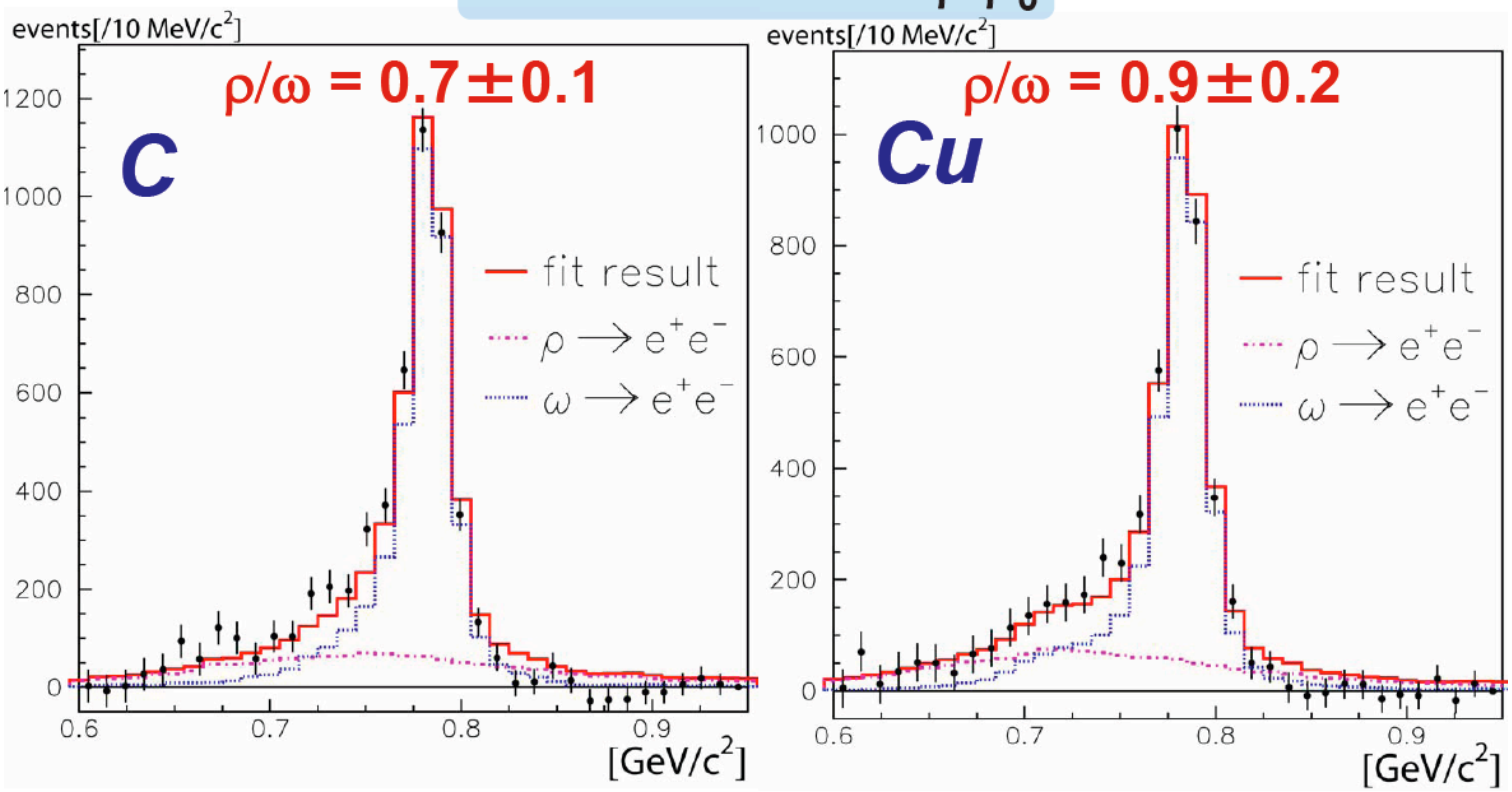
"ρ/ω is consistent with zero (0.0+/-0.02(stat)+/-0.2(sys) and 0.0+/-0.04(stat)+/-0.30 (sys)) It is pretty much surprising because the ρ/ω is known to be unity in pp interaction (PLB48(74)73)"

KEK-PS E325 cont

M. Naruki et al, PRL 96 (2006) 092301

Subtract the background and constrain the ω/ρ ratio to include ρ
Using a model that predicts the probability for ρ mesons decaying inside the nucleus.

$$m^*/m = 1 - 0.092\ \rho/\rho_0$$

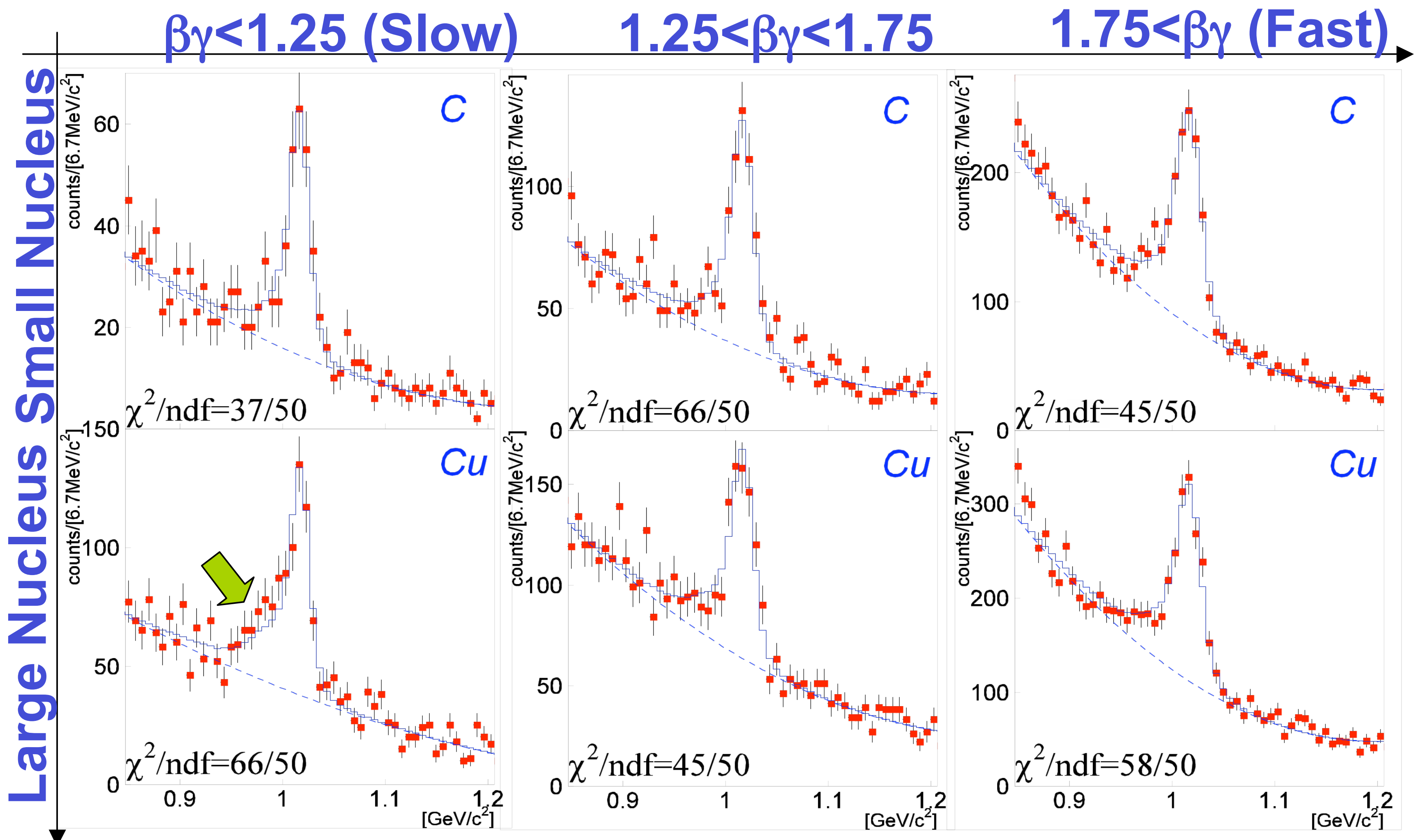


α = 0.092 +/- 0.002

"the fit … reproduces the data qualitatively well"

KEK-PS E325

Invariant Mass Spectrum of e^+e^- (ϕ meson)



KEK E325 fit results

$$m^*/m = 1 - k_1\, \rho/\rho_0,$$
$$\Gamma^*/\Gamma = 1 + k_2\, \rho/\rho_0$$

Best Fit Values		
	ρ, ω	ϕ
k_1	$9.2 \pm 0.2\%$	$3.4^{+0.6}_{-0.7}\%$
k_2	0 (fixed)	$2.6^{+1.8}_{-1.2}$
ρ/ω	0.7 ± 0.1 (C) 0.9 ± 0.2 (Cu)	-

Enyo et al (YKIS2006)

Photoproduction of Vector Mesons off Nuclei
"looking for medium modifications"

$$\gamma A \longrightarrow VX$$
$$\qquad\qquad\qquad \hookrightarrow e^+e^-$$

- **Jlab Experiment E01-112 (also called g7)**

  Spokespersons: C. Djalali (USC), M. Kossov (ITEP),

  D. Weygand (Jlab)

- **Photon beam (minimal disturbance to initial sate) :**

  E_γ ~ .6 to 3.8 GeV (tagged γ)

  Targets: LD_2, C, Ti, Fe, (Pb)

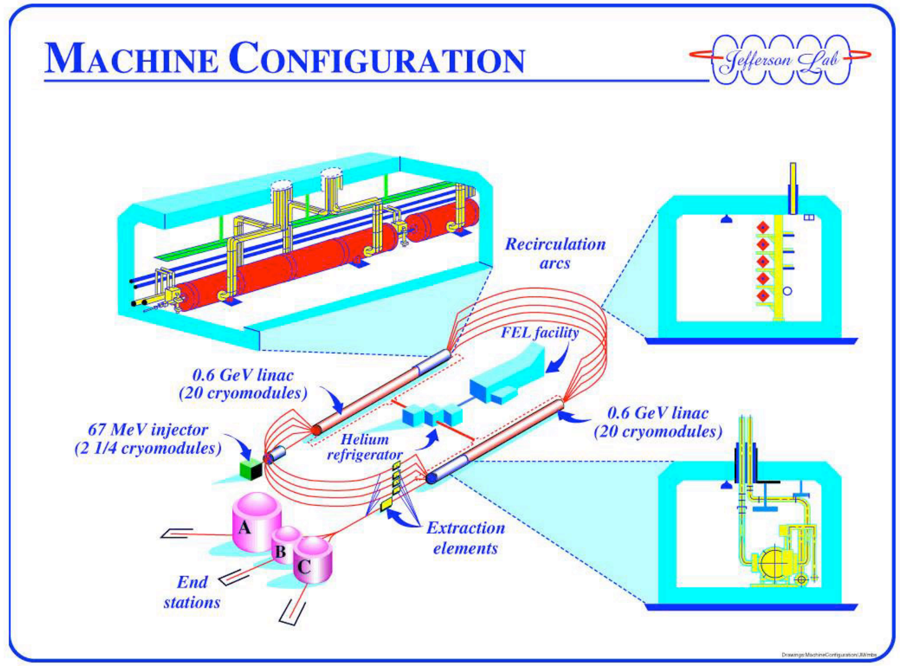
- **Leptonic decay :**

  Almost no final state interaction! HOWEVER (NO FREE LUNCH!)

  Low branching ratio : ~5 10^{-5}

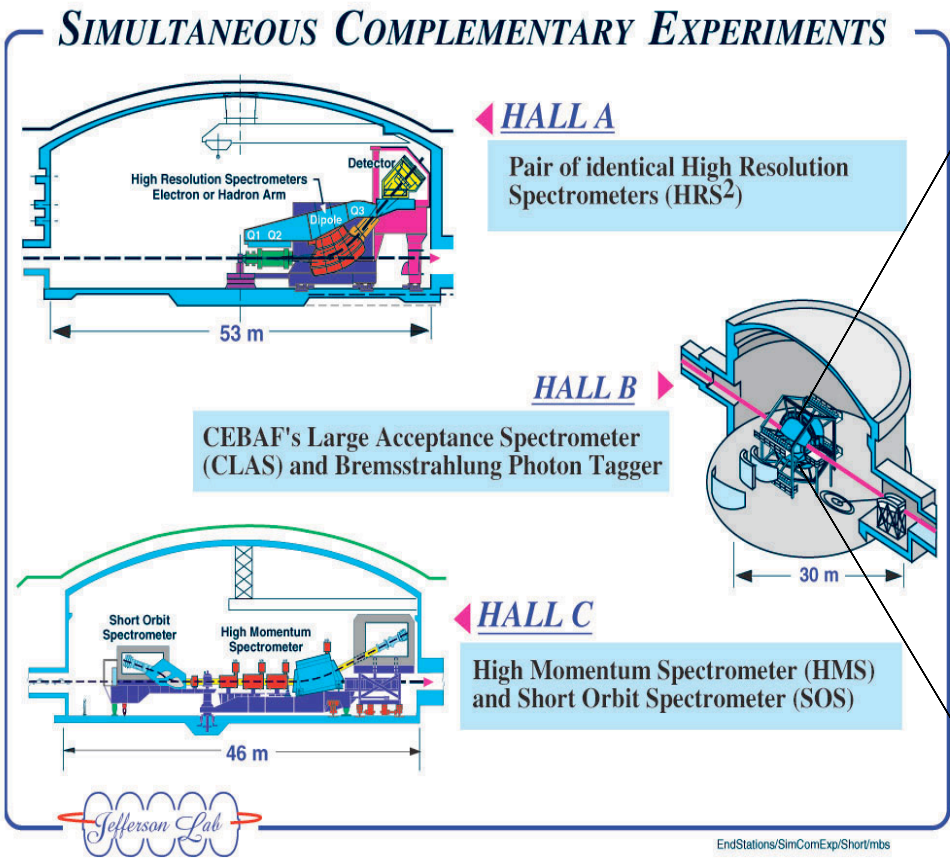
  needs high photon flux : 5 10^7 tagged γ/s

CEBAF (Continuous Electron Beam Accelerator Facility)
At JLab (Jefferson Laboratory) at Newport-News (VA, USA)



Superconducting Electron Accelerator (338 cavities), 100% duty cycle, I_{max}=200 μA, E_{max}=6 GeV, $\delta E/E=10^{-4}$.
1500 physicists, ~30 countries, operational since end of 97

Three Halls

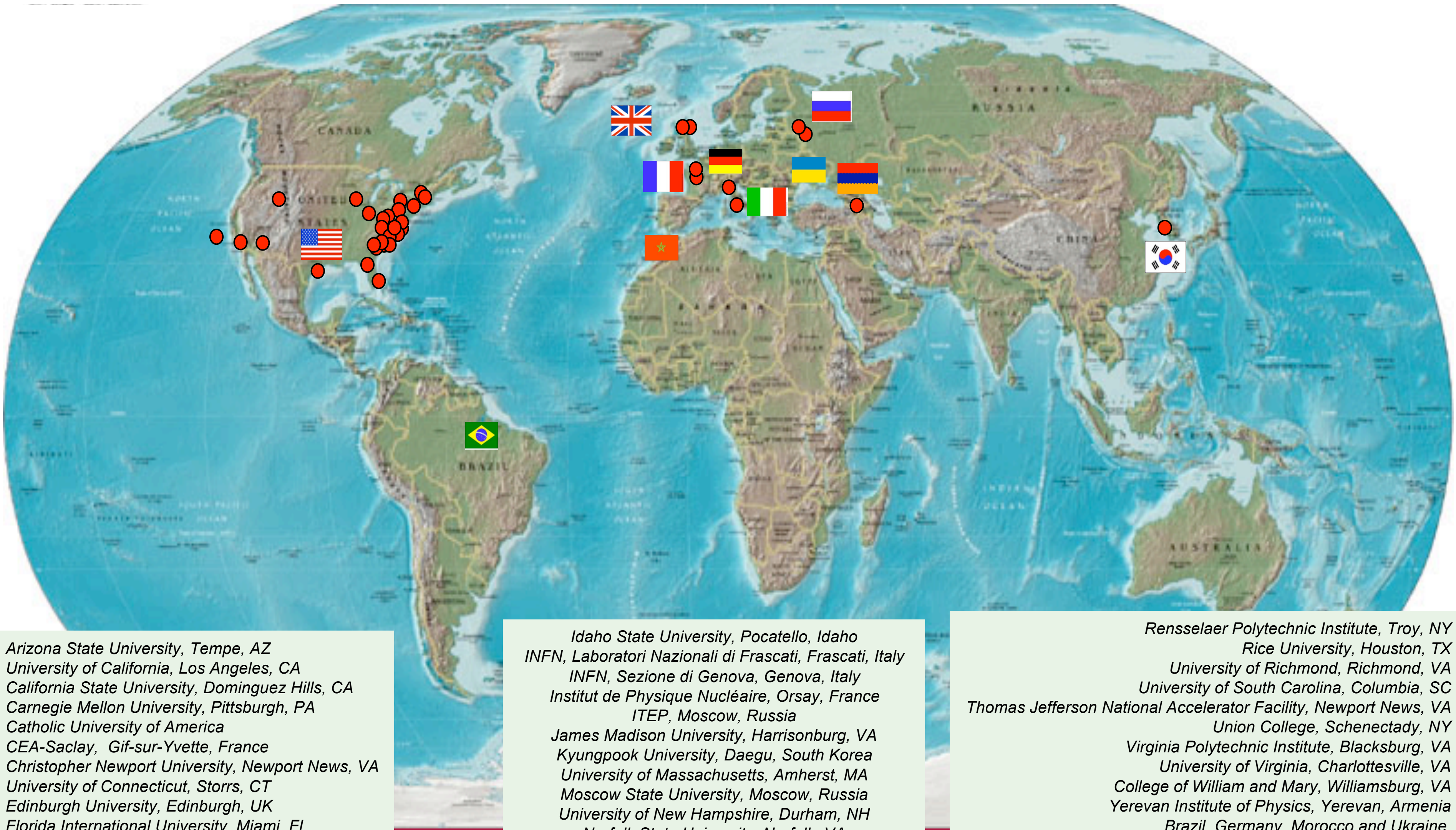


The 3 experimental halls can run simultaneously

In Hall B, the CLAS detector(CEBAF Large Acceptance Spectrometer) : Electrons and (tagged) Photon beams

The CLAS Collaboration

~200 physicists from ~ 40 institutions (>10 countries)



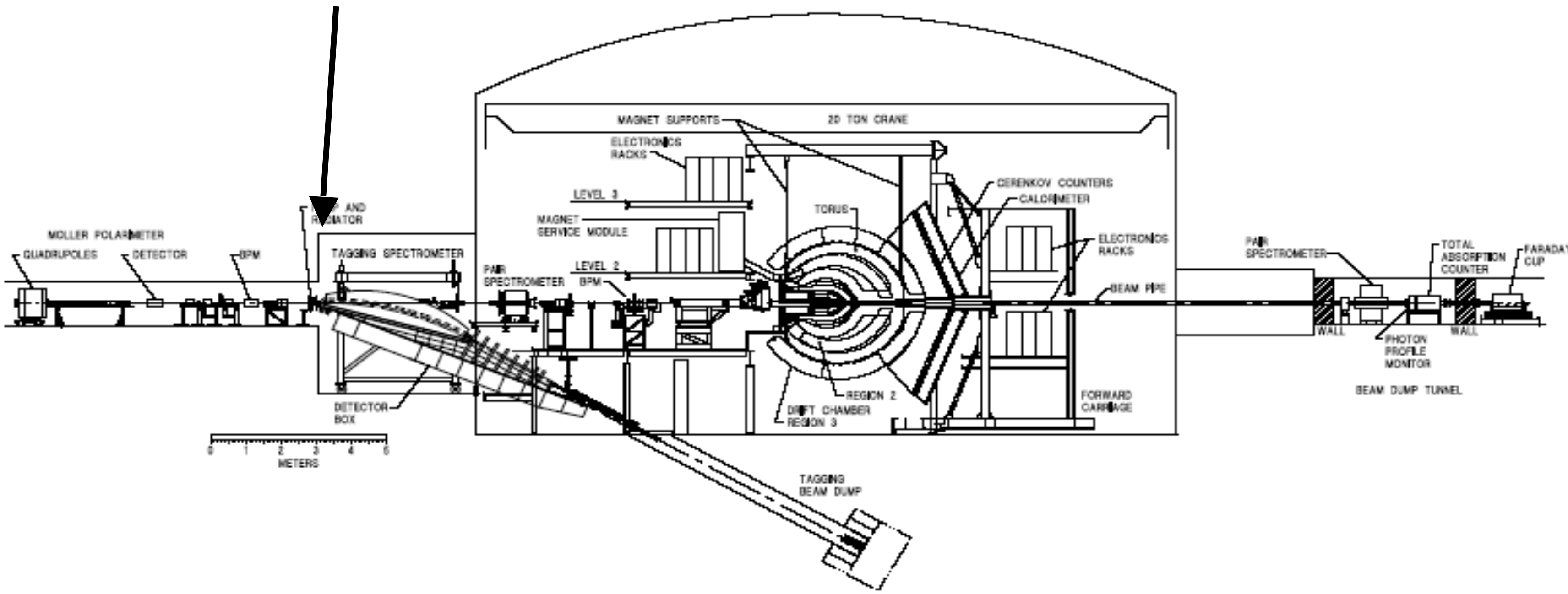
Arizona State University, Tempe, AZ
University of California, Los Angeles, CA
California State University, Dominguez Hills, CA
Carnegie Mellon University, Pittsburgh, PA
Catholic University of America
CEA-Saclay, Gif-sur-Yvette, France
Christopher Newport University, Newport News, VA
University of Connecticut, Storrs, CT
Edinburgh University, Edinburgh, UK
Florida International University, Miami, FL
Florida State University, Tallahassee, FL
George Washington University, Washington, DC
University of Glasgow, Glasgow, UK

Idaho State University, Pocatello, Idaho
INFN, Laboratori Nazionali di Frascati, Frascati, Italy
INFN, Sezione di Genova, Genova, Italy
Institut de Physique Nucléaire, Orsay, France
ITEP, Moscow, Russia
James Madison University, Harrisonburg, VA
Kyungpook University, Daegu, South Korea
University of Massachusetts, Amherst, MA
Moscow State University, Moscow, Russia
University of New Hampshire, Durham, NH
Norfolk State University, Norfolk, VA
Ohio University, Athens, OH
Old Dominion University, Norfolk, VA

Rensselaer Polytechnic Institute, Troy, NY
Rice University, Houston, TX
University of Richmond, Richmond, VA
University of South Carolina, Columbia, SC
Thomas Jefferson National Accelerator Facility, Newport News, VA
Union College, Schenectady, NY
Virginia Polytechnic Institute, Blacksburg, VA
University of Virginia, Charlottesville, VA
College of William and Mary, Williamsburg, VA
Yerevan Institute of Physics, Yerevan, Armenia
Brazil, Germany, Morocco and Ukraine,
as well as other institutions in France and in the USA,
have individuals or groups involved with CLAS,
but with no formal collaboration at this stage.

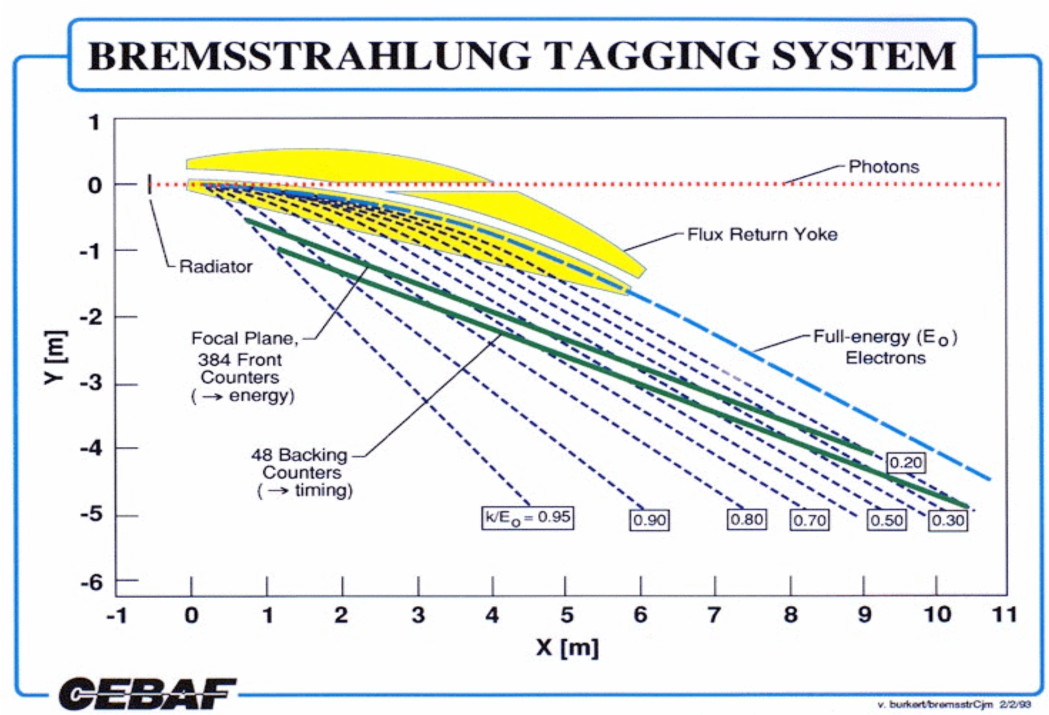
3. 10^{-4} RL
Radiator

<u>TAGGER in HALL B</u>



Flux ~ $5x10^7$ γ/s, Can Tag γ with E_γ between 0.2 and 0.95 of E_e

The photon beam (the tagger)



- Photon beam is created by bremsstrahlung using a radiator located on the beam line.
- Energy distribution is $dN(k) \propto \frac{1}{k} dk$
- Electrons are removed from the beam axis using a magnetic dipole and bent onto 2 planes of scintillators.
- The tagger covers [20%, 95%] of the incident electron's energy range.
- The tagger allows to tag the photon with an energy and a time.

Bremsstrahlung Tagging Spectrum (20%-95%)

- $E(e^-)$ = 3.0 GeV $E(\gamma)$ = 0.60 - 2.85 GeV
- $E(e^-)$ = 4.0 GeV $E(\gamma)$ = 0.80 - 3.80 GeV

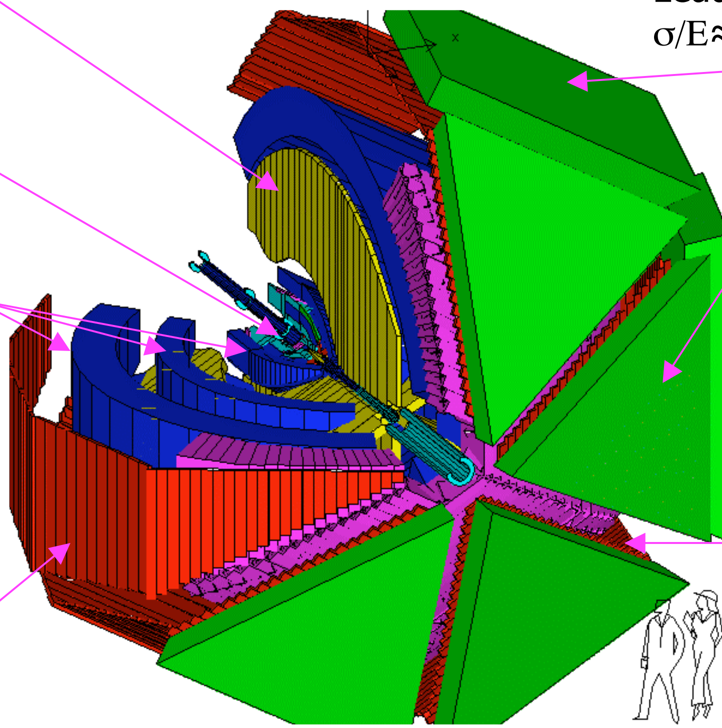
The Cebaf Large Acceptance Spectrometer

Torus magnet
6 superconducting coils
$\int B \cdot dl \approx 1.7\ \ Tm$

Liquid D_2 (H_2)target +
γ start counter; e minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells
$\sigma \approx 300 \mu m$

Electromagnetic calorimeters
Lead/scintillator, 1296 photomultipliers
$\sigma/E \approx 10\%/E^{1/2}$

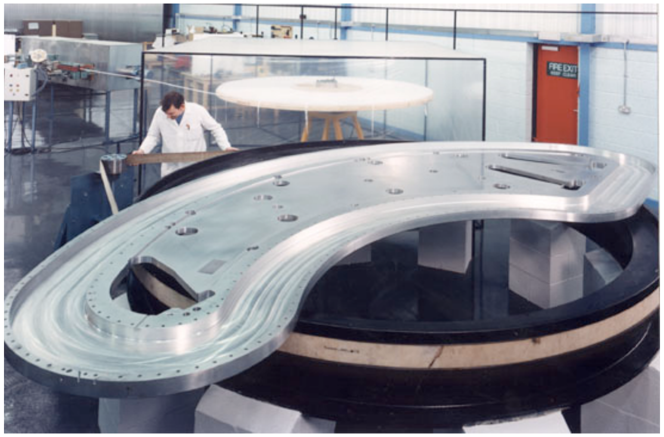


Gas Cherenkov counters
e/π separation, 256 PMTs
99.5% efficient over 55 m^2 area

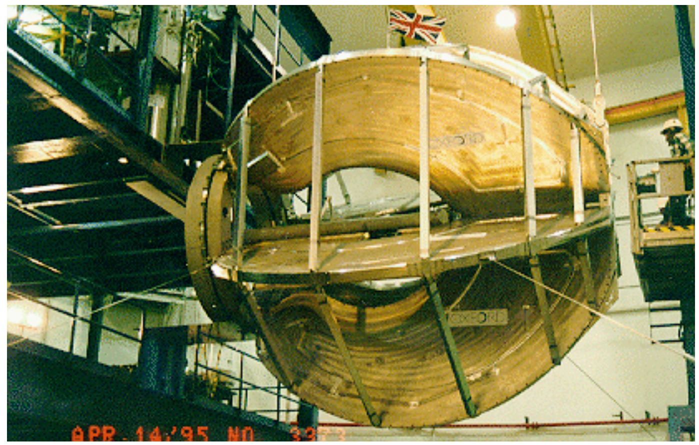
Time-of-flight counters
plastic scintillators, 684 photomultipliers
$\sigma \approx 145 ps$

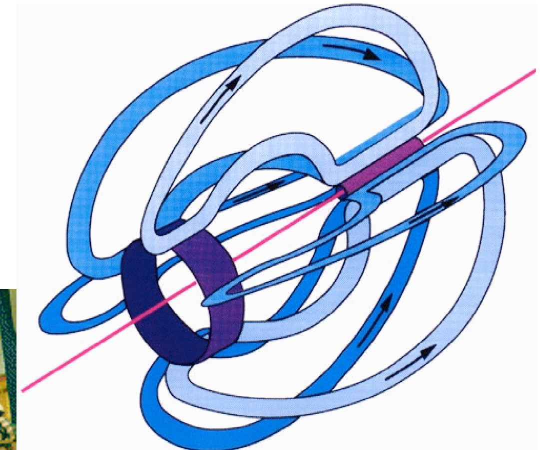
Mecking et al., Nucl. Inst. Meth., **A** 503 (2003) 513.

The magnetic field is strong at forward angles becoming weaker at larger angles. Almost magnetic field free target region



six kidney-shaped coils

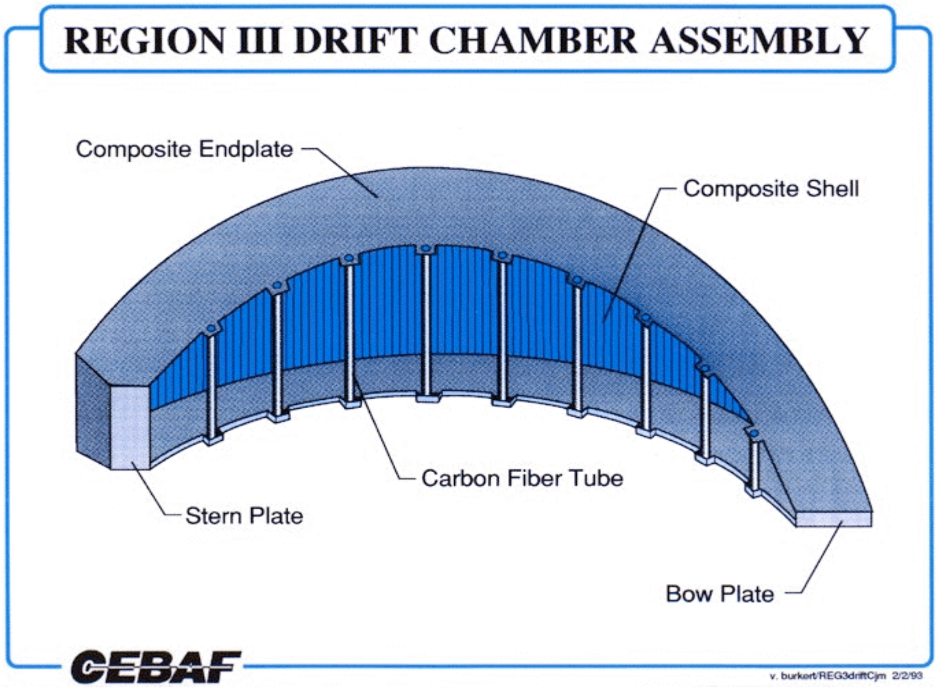


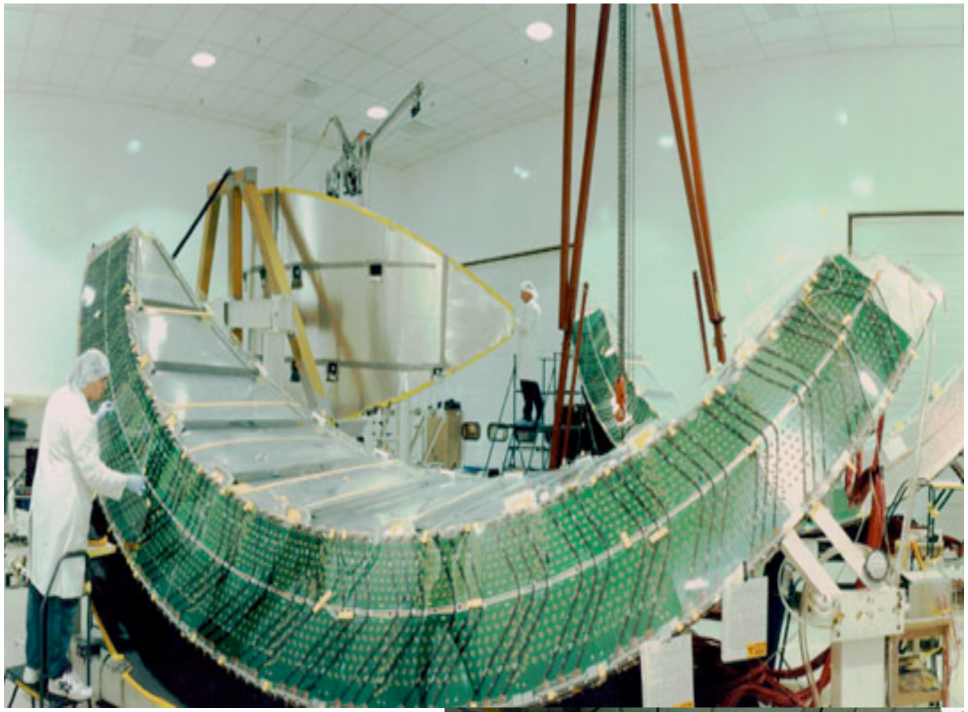


6 superconducting coils separated by 60^o in ϕ produce a toroidal magnetic field with a symmetry around the beam axis (azimuthal symmetry)

Charged particles are bent in θ but not in ϕ

$$\int B.dl \sim 2 \text{ Tm } (\theta \sim 12^o)$$
$$\sim .5 \text{ Tm } (\theta > 90^o)$$



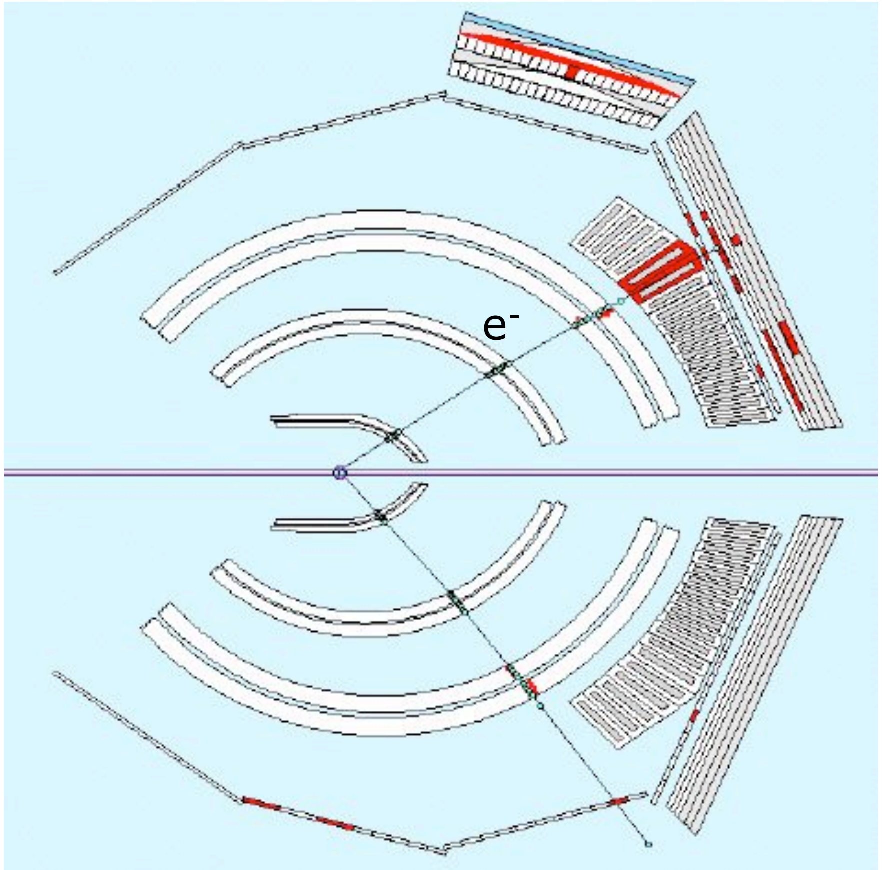


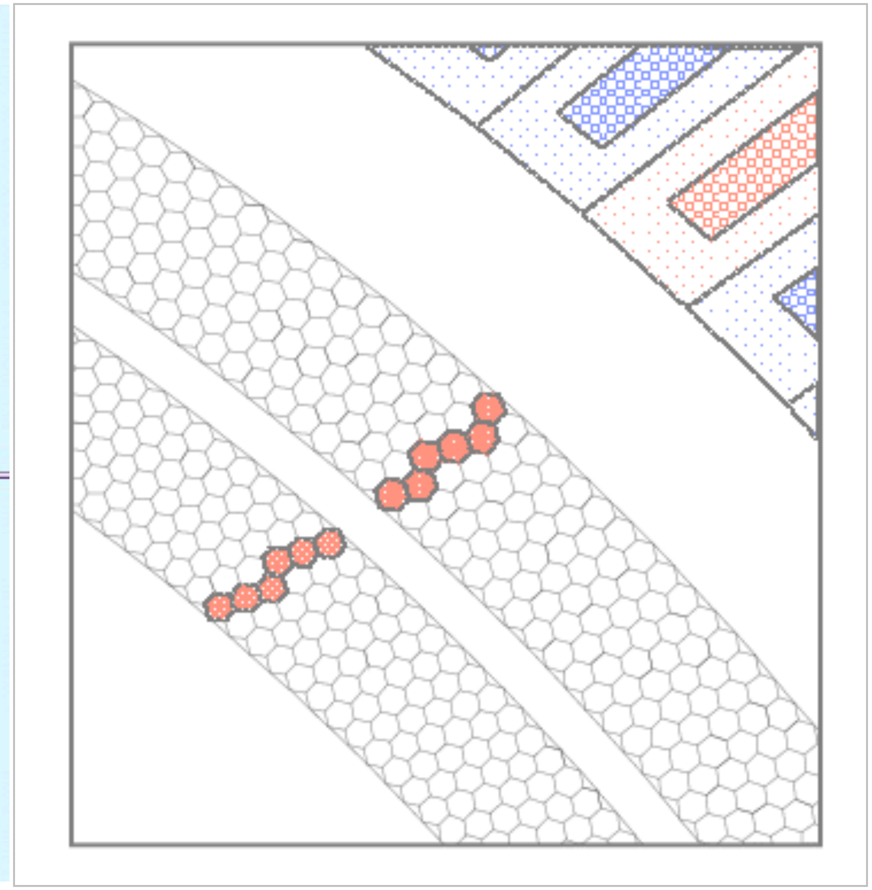
Three tracking regions :

Around the target (~1m, low field)
Close to the coils (~2m, strong field, maximum curvature)
Beyond the coils (~3m, low field).

Each region has 2 "super layers" :

axial/parallel to B
with a stereo angle of 6° **(info. in ϕ)**





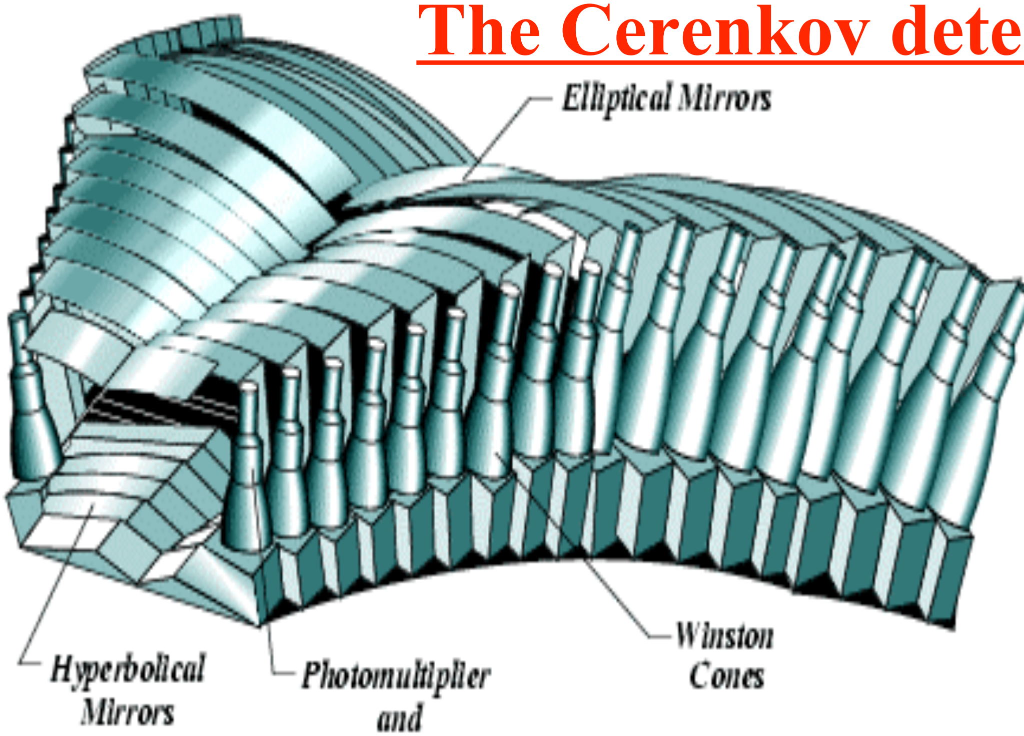
Designed to detect the trajectory of charged particles

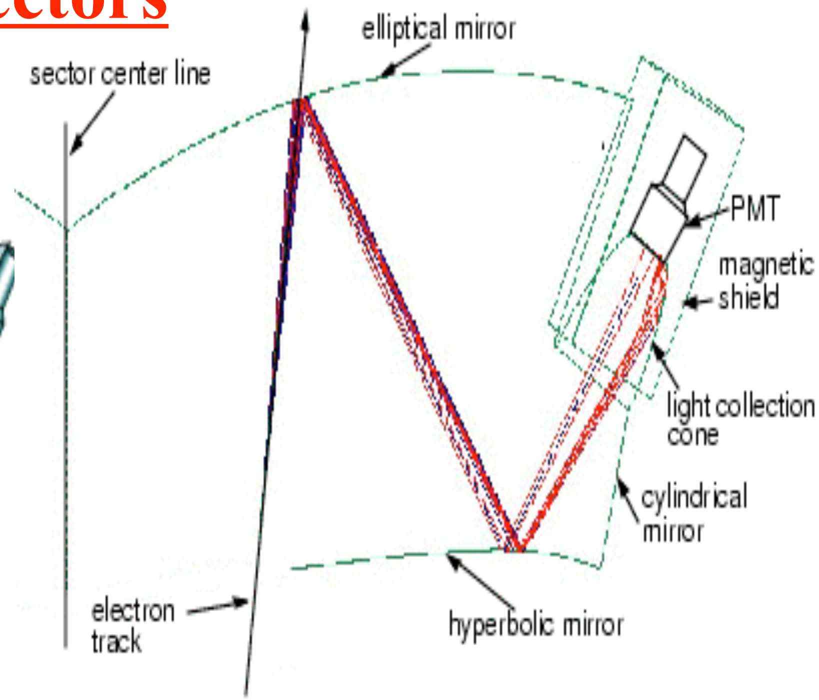
p>150 MeV/c and $8^o < \theta < 142^o$ (up to 80% in ϕ)

$\delta p/p \sim .5$-1%, $\delta\theta$, $\delta\phi$ < 2mrad

[Field setting: (-) in bending; (+) out bending]

The Cerenkov detectors





Electron trigger, e/π discrimination,

Angular coverage: 8º to 45º in θ and 60º in φ,

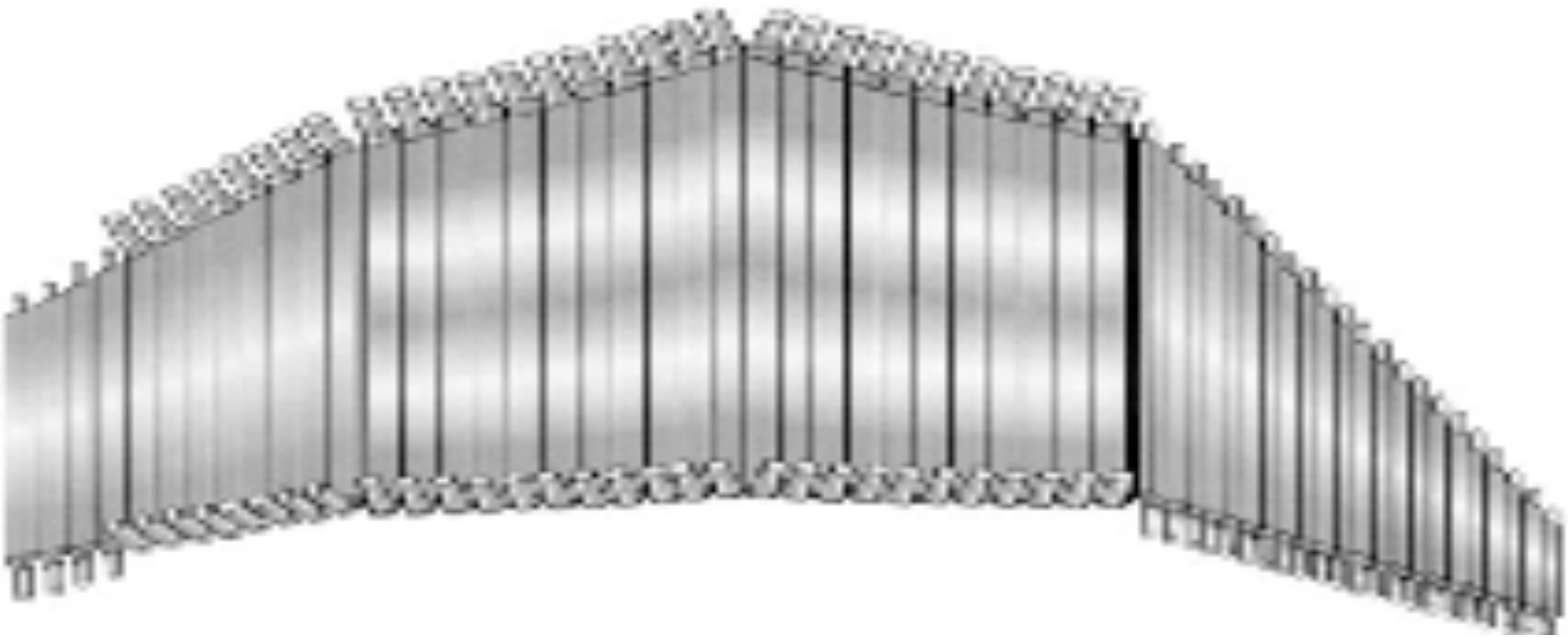
Focus the Cerenkov light on the PMT (5 in. Phillips XP4500B) located in the shadow of the main torus coils,

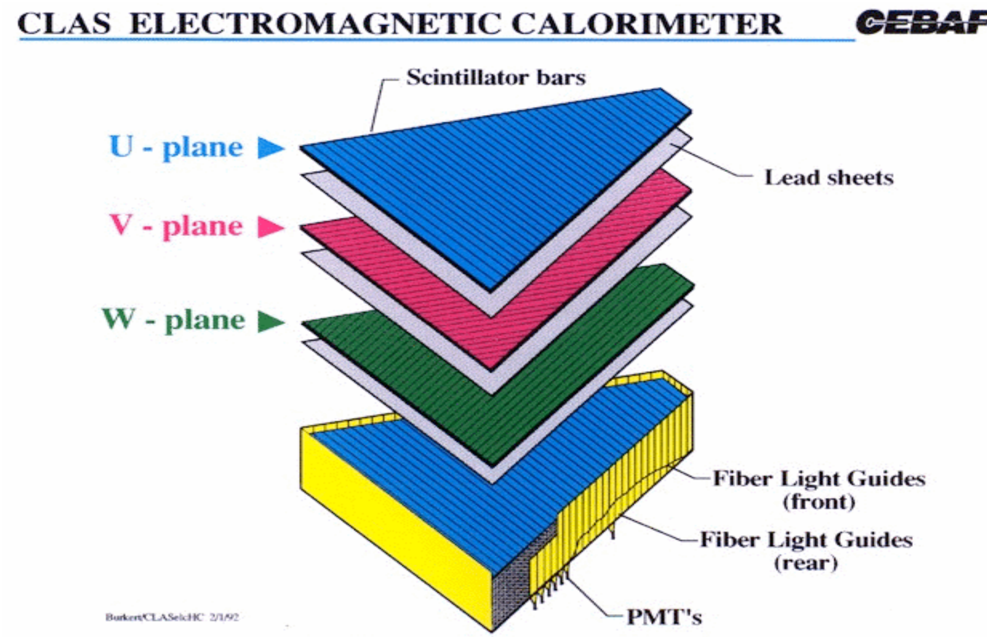
Each module : 2 focusing mirrors (aluminum), 1 cylindrical mirror et 1 collecting the light (216 in total).

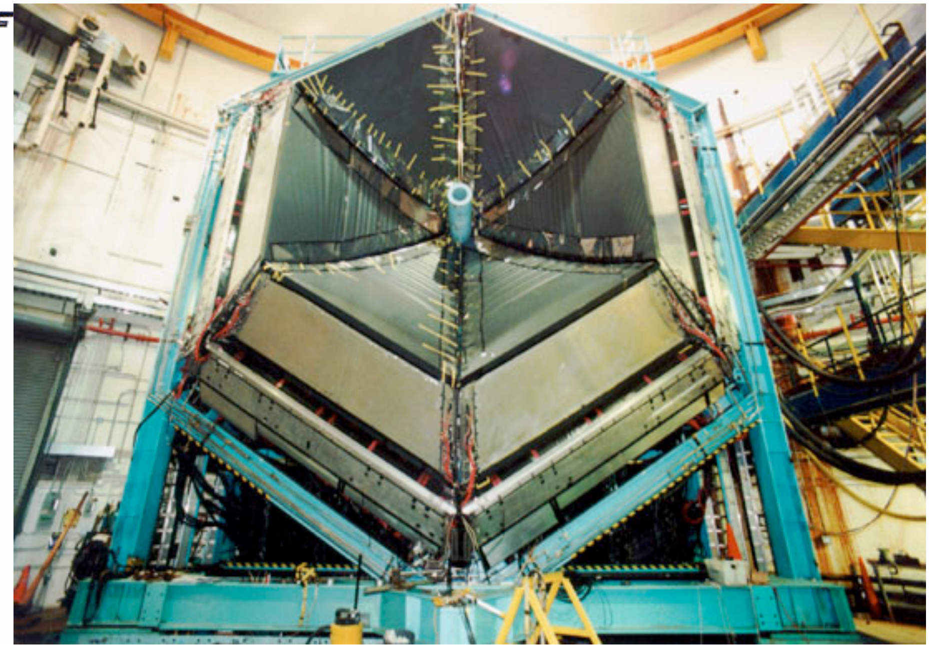
The time of flight system

75 scintillators per sector between 8^o and 142^o (206 m^2)

- Length : from 32 to 450 cm,
- Thickness : 5 cm,
- Width : 15 cm and 22 cm.

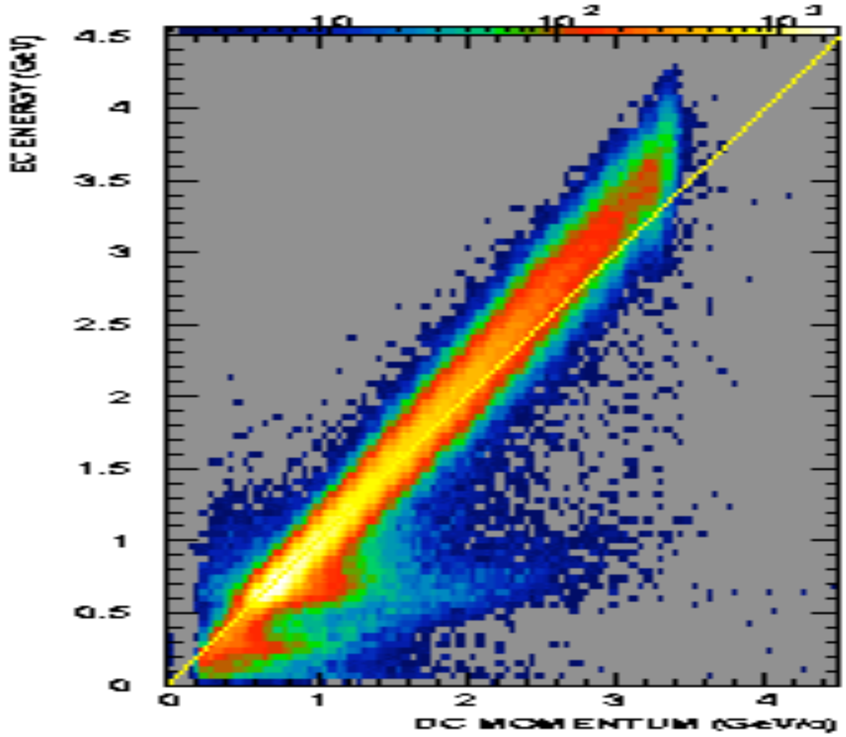


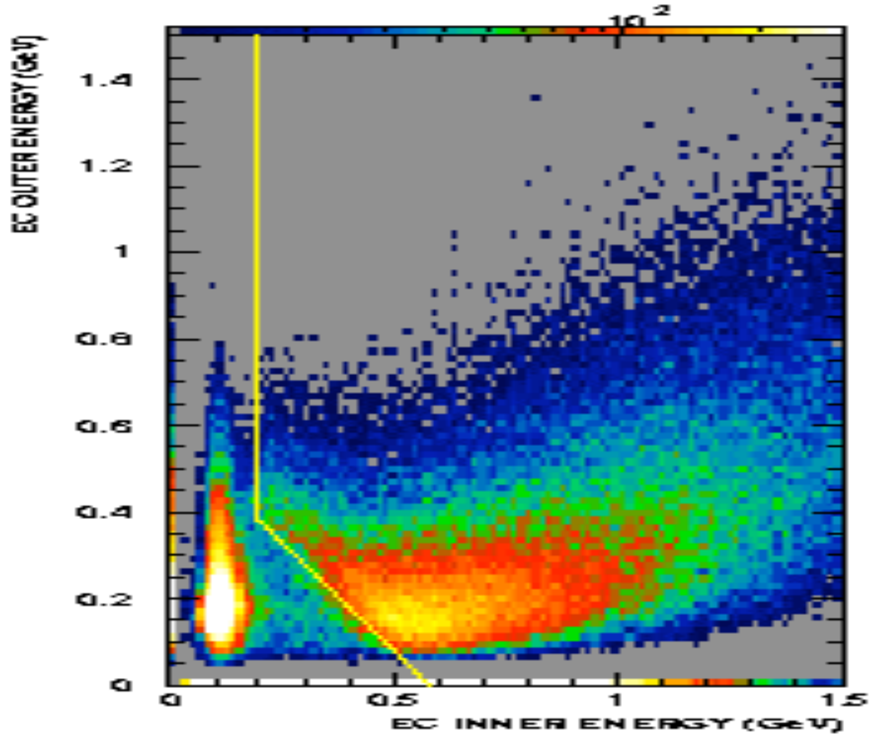




- Surface = equilateral triangle ($8m^2$), volume = truncated pyramid, located at 5 m from the target and covering $8^o<\theta<45^o$;
- 39 layers of 1cm scintillator + 2.2 mm sheets of Pb (16λ)
- Each layer of scintillators is divided in 36, parallel to each side of the triangle ; this orientation changes by 120^0 for each new layer => 3 orientations (U,V,W)=>Cells of ~10 cm ;
- EC divided in inner (15 layers) et outer (24 layers) parts
  – 5 to 8 successive scintillators are read by a single PMT

ELECTRON IDENTIFICATION





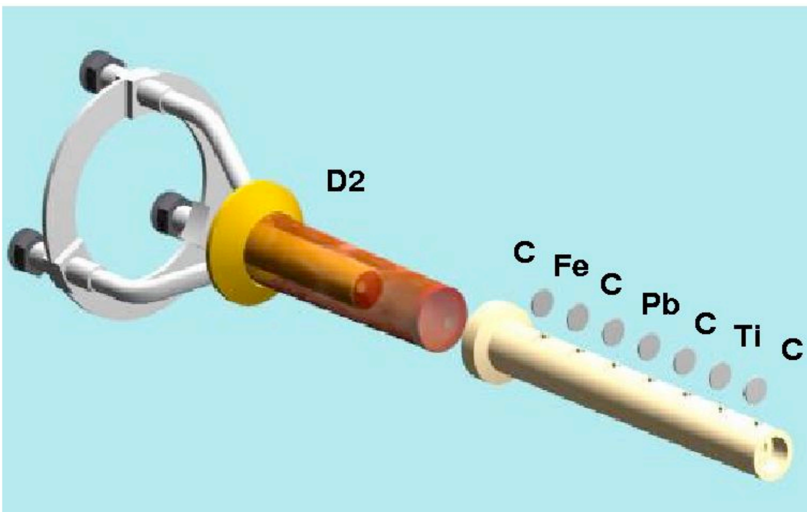
For e, correlation between the energy measured by the EC and the momentum measured by the DCs,

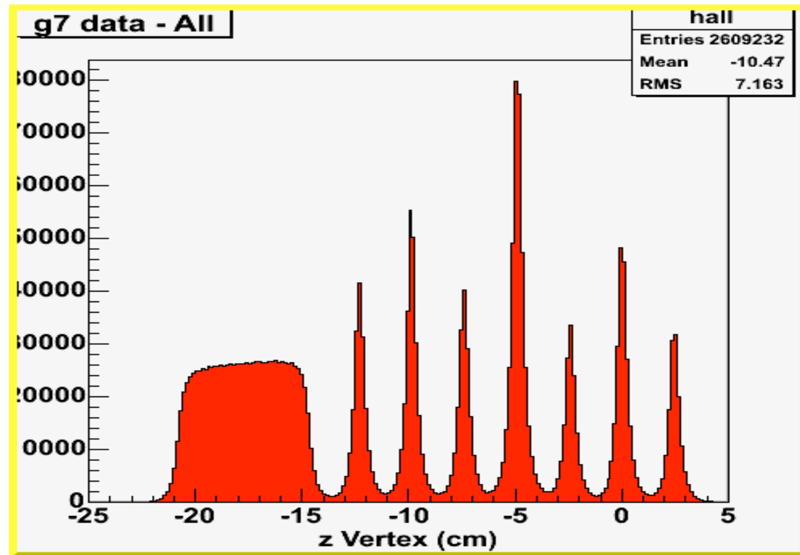
Most of the pions are rejected by the threshold on the total energy in the EC : 0.6 GeV > 2δE(MIPs))

Most of the e deposit their energy in the front (inner) part of the EC (the pions deposit very little energy in the inner part and a lot in the back (outer) part of the EC)

Multi-Segment Nuclear Target

- Contains materials with different average densities.
- LD2 and seven solid foils of C, Fe, Pb, and Ti.
- Each target material 1 g/cm^2 and diameter 1.2 cm



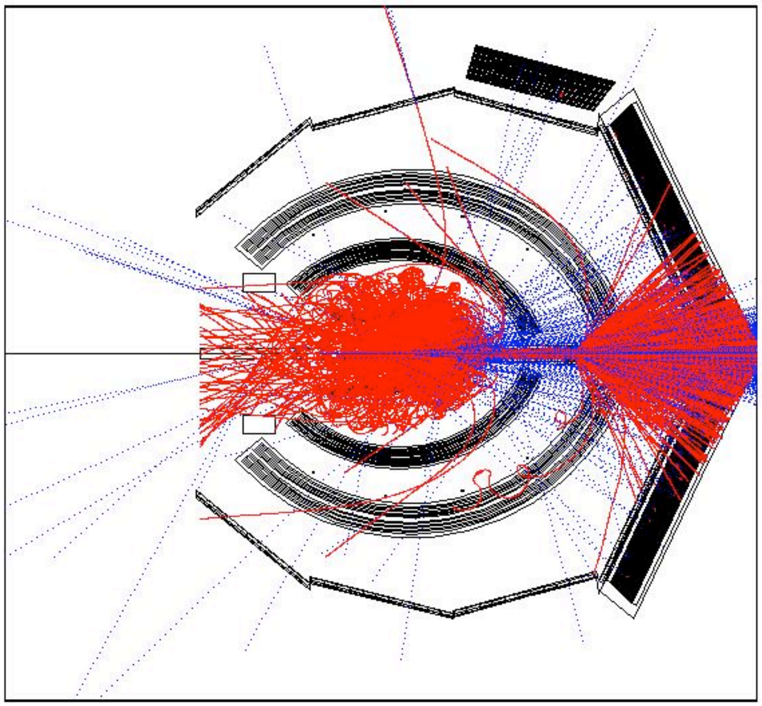


- Proper spacing 2.5 cm to reduce multiple scattering
- Deuterium target as reference, small nucleus, no modification is expected.

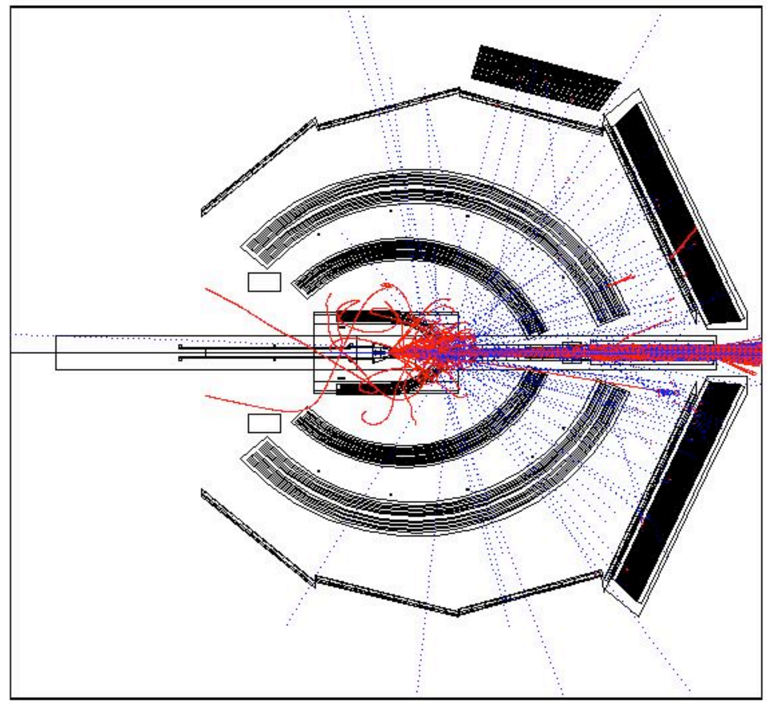
Mini-torus around Target

-g7 first experiment using Z>4 targets in CLAS

Photons + heavy targets ---> huge low energy pairs



Without Mini Torus

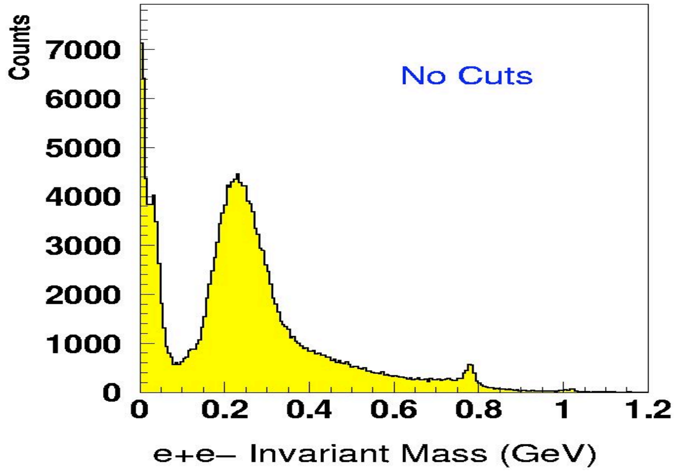


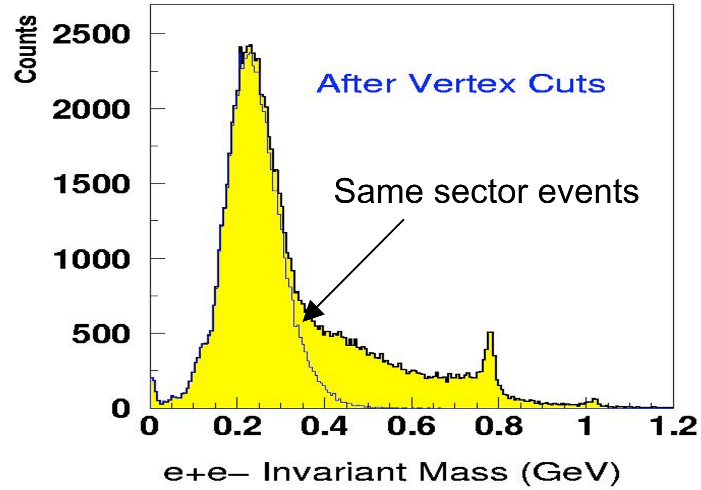
With Mini Torus

Substantially less bkgd with Mini Torus

e^+e^- Invariant Mass Spectra

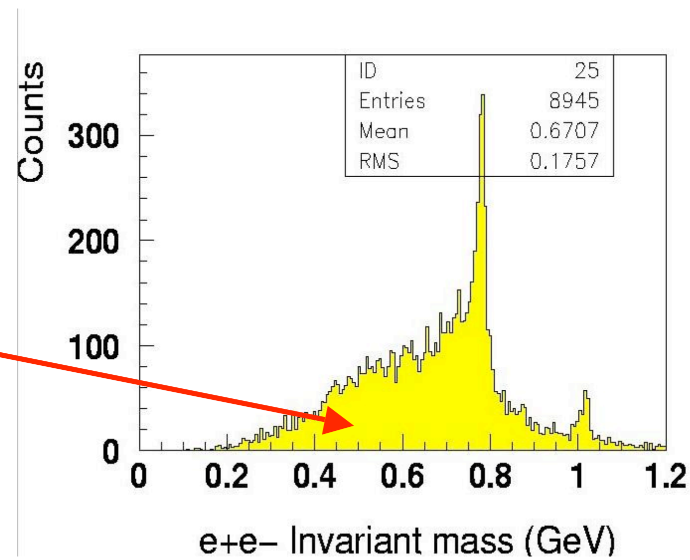
- Excellent π/e discrimination: 5.4×10^{-4} for one and 2.9×10^{-7} for two arms.





- Vertex, EC, CC, timing cuts
- Momentum corrections
- Target energy loss corrections
- Lepton momentum cuts

Caution: The treatment of the background may change the estimation of the signal (ρ).



Possible channels that contribute to the e+e- mass spectrum

Correlated:

- **Monte-Carlo simulations using a model (BUU) by Mosel et al. (*Nucl. Phys. A671, 503 (2000))* including various decay channels and nuclear effects, and CLAS detector simulation package (GSIM) Simulations with BUU includes all the e+e- decay channels with same strength.**
  - $\omega \rightarrow$ e+e-, $\rho \rightarrow$ e+e-, $\phi \rightarrow$ e+e-
  - $\eta \rightarrow \gamma$ e+e-
  - $\omega \rightarrow \pi^0$ e+e-

Giesssen BUU Code

"Semi-correlated":

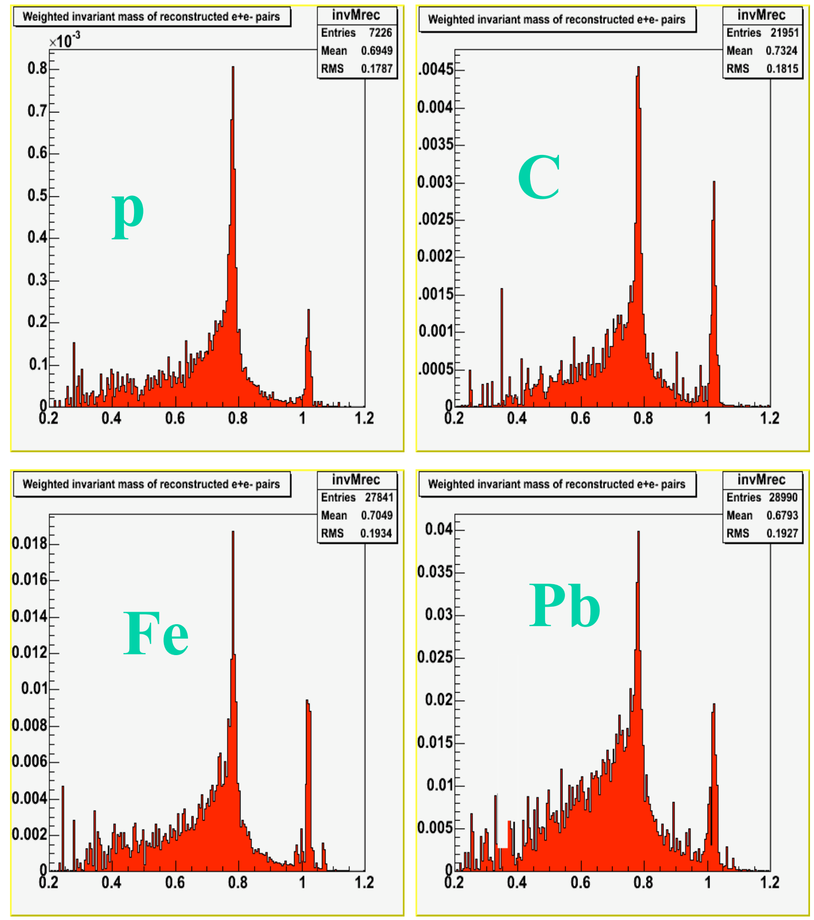
• Bethe-Heitler	calculated by Mosel's group $\rightarrow$ negligible
• $\gamma A \rightarrow \pi^0 \pi^0 X \rightarrow \gamma$ e+e- γ e+e-	2 π^0 Dalitz decay mixed $\rightarrow$ negligible
• $\pi^0 \rightarrow$ e+e- e+e-	double Dalitz $\rightarrow$ low mass

Uncorrelated:

- **Mixed event technique. Pairs of identical (e+e+, e-e-) leptons, which are produced only by combinatorial background provide a natural normalization and samples of uncorrelated particles.**

G7 "cocktail" BUU predictions

- Monte-Carlo simulations based on Giessen code using the BUU transport equations *[Mosel et al. Nucl. Phys. A671, 503 (2000)]*
- The code includes various decay channels and nuclear effects, and CLAS detector simulation package (GSIM)
- Generates 7 channels: e^+e^- decays of the ρ, ω and ϕ + Dalitz decays of the π^0, η, ω and Δ.
- Includes conventional medium effects such as Pauli blocking, shadowing for photon induced reactions, Fermi motion of nucleons, collisional broadening (targets other than proton).
- Can add a mass shift according to the Hatsuda and lee formula on demand.



$$\frac{m_V^*}{m_V} = 1 - \alpha \frac{\rho_B}{\rho_0}$$

Uncorrelated events

The mixed-event technique: What is "combinatorial background"?

The combinatorial background is the random combination of pairs (e^+e^-, e^-e^-, and e^+e^+) due to the uncorrelated sources.

Which belongs to which?

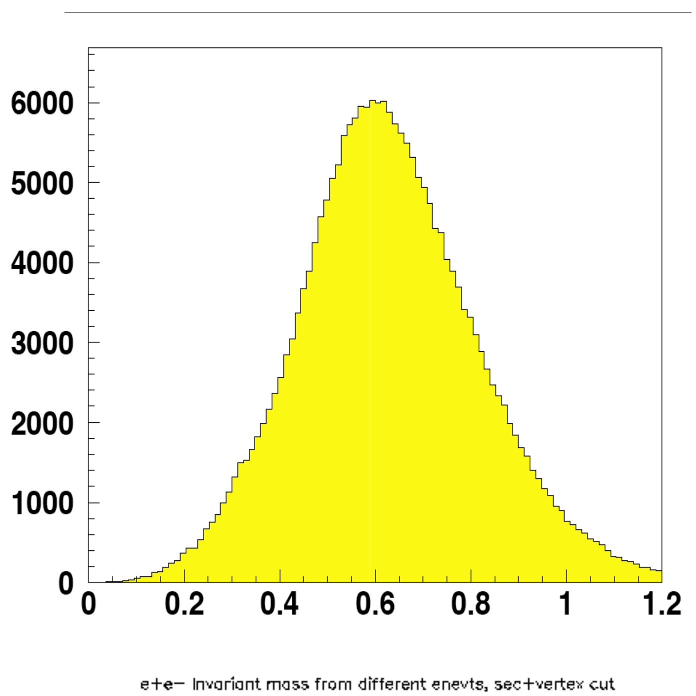
$\gamma \rightarrow$ e+ e- $\quad$ $\gamma \rightarrow$ e+ e- $\quad$ $\gamma \rightarrow$ e+ e- $\quad$ $\gamma \rightarrow$ e+ e-

$\pi^0 \rightarrow \gamma$ e+ e- $\quad$ $\pi^0 \rightarrow \gamma$ e+ e- $\quad$ $\pi^0 \rightarrow \gamma$ e+ e- $\quad$ $\pi^0 \rightarrow \gamma$ e+ e-

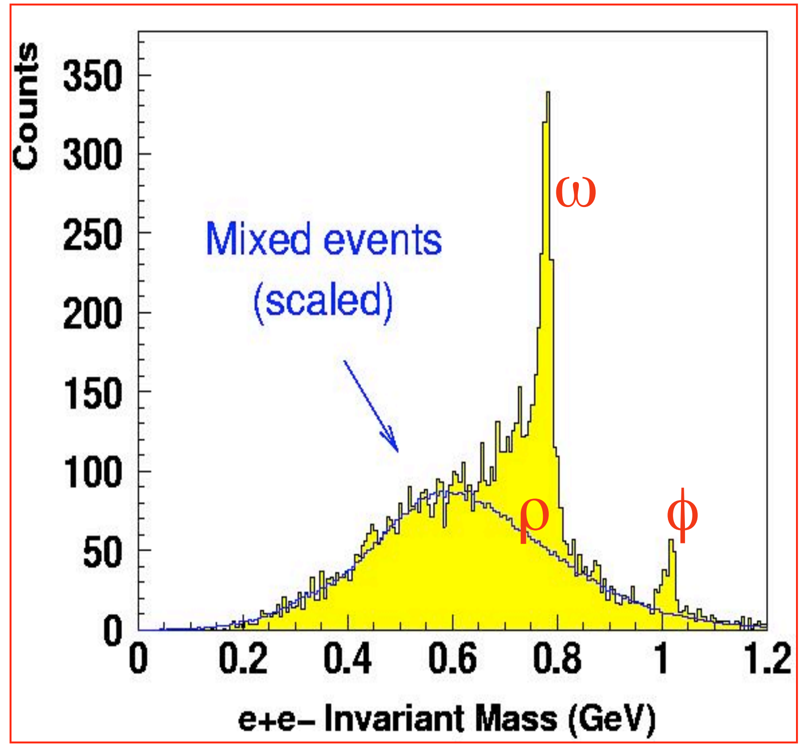
1) Mix e^+ and e^- from different events, use the same acceptance as data to get shape for the uncorrelated background. The normalization of the background comes out of the best fit.

2) Use yield of pairs of identical (e+e+, e-e-) leptons, which are produced only by combinatorial processes, will provide both a natural normalization and shape for the uncorrelated background

1) Mixed events BKGD

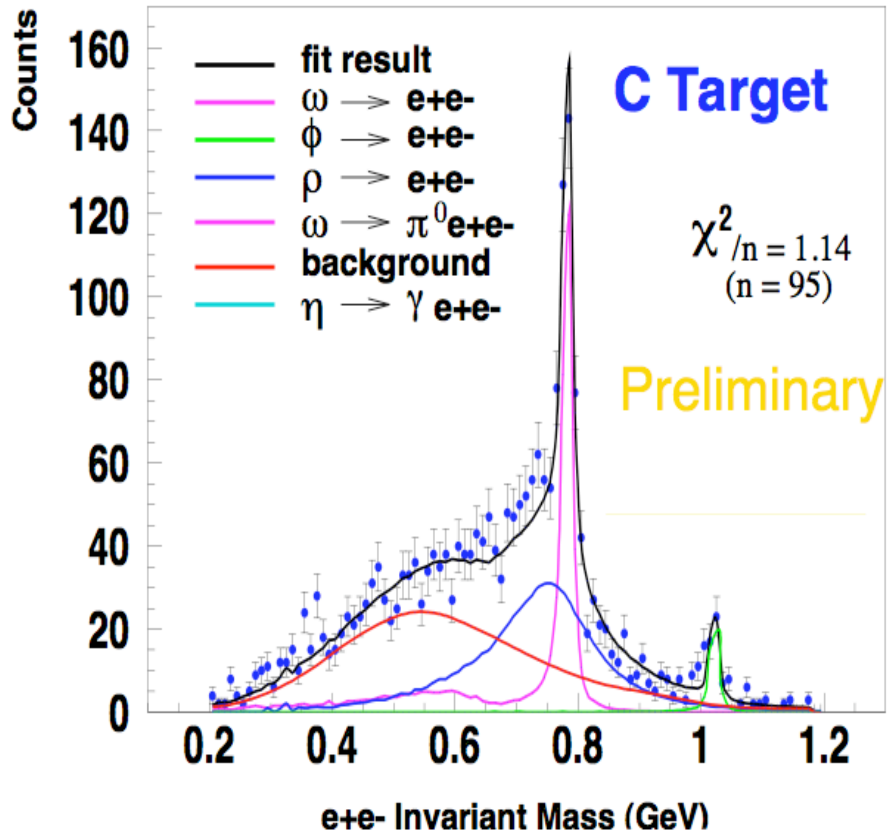


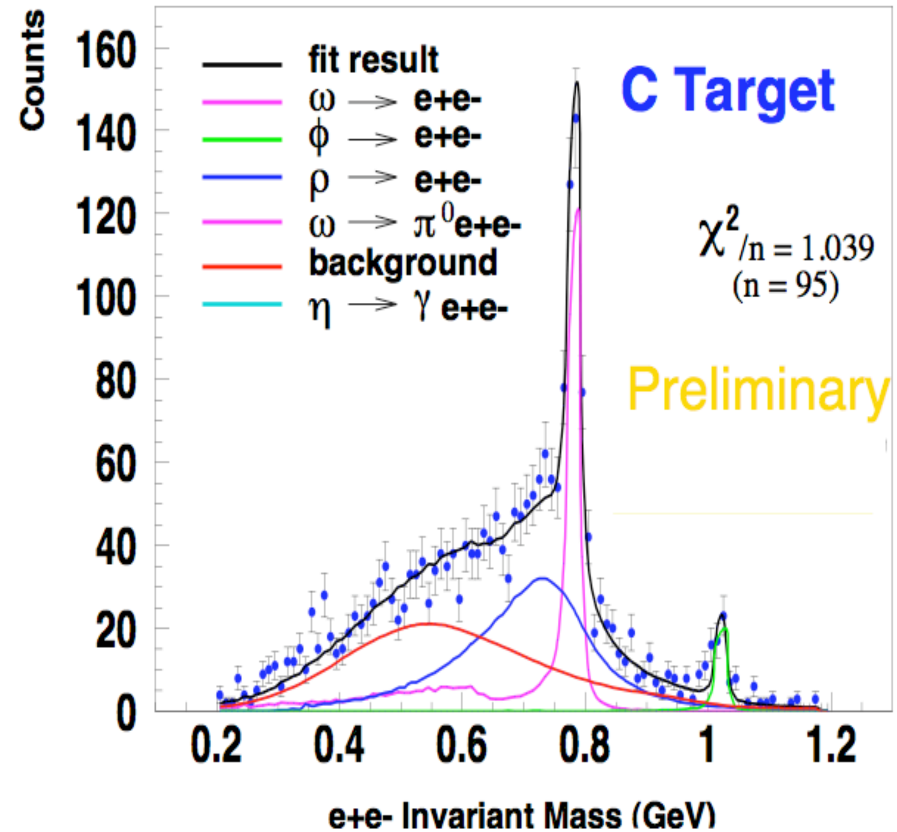
Mixed events background shape for g7 – with sector cuts as data



In Blue: Scaled combinatorial background superimposed on g7 data

Fit Results for C

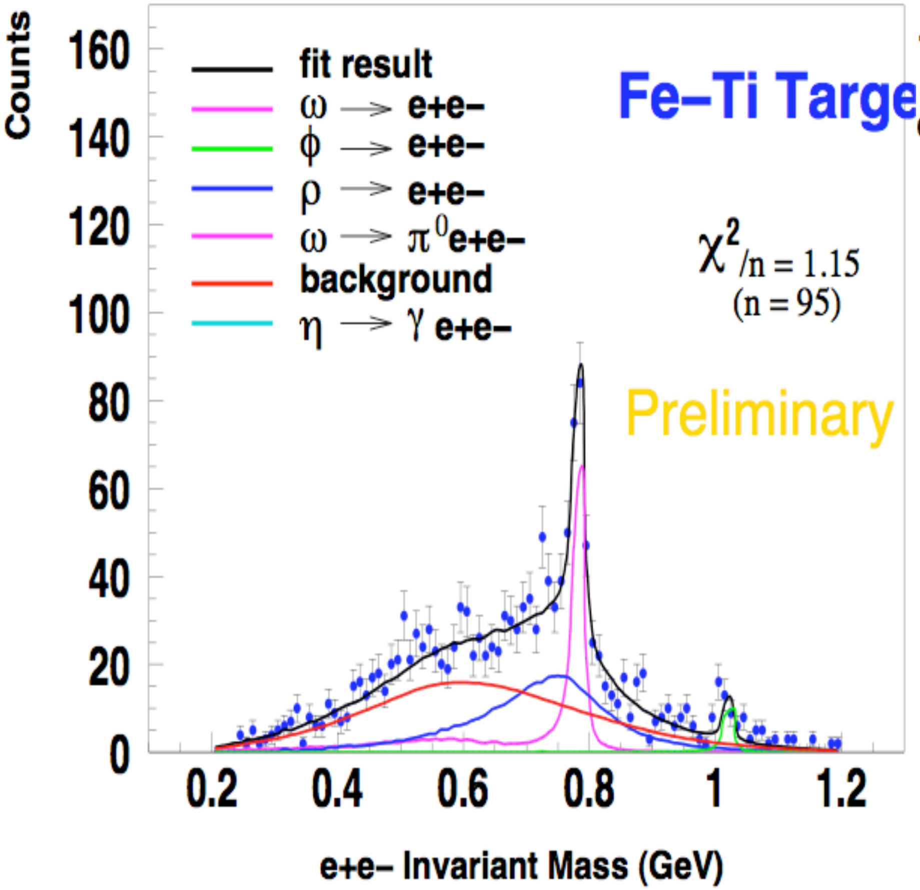


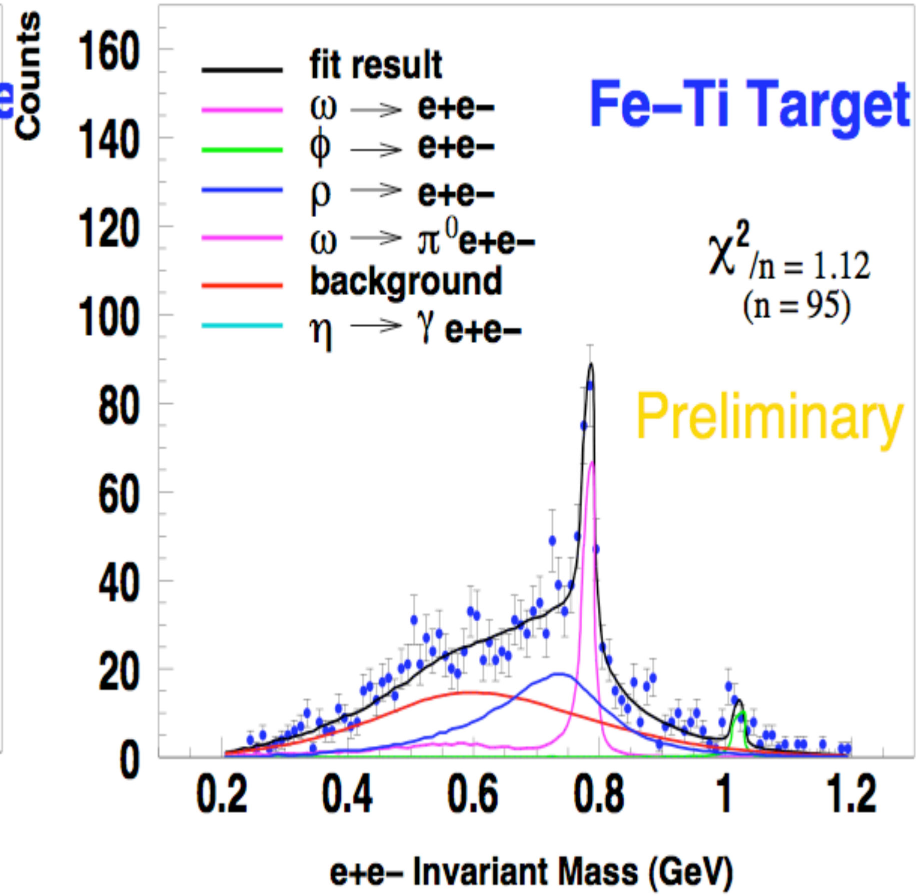


No modification α=0

With modification a la HL α~0.16

Fit Results for Fe + Ti





No modification α=0

With modification a la HL α~0.16

Preliminary conclusions using mixed event shape only

-From χ_2 fit one might conclude (although limited stat) that the data can accommodate a downward mass shift.

-Spectral shape of ρ not well "defined", the "free to move" background (i.e normalization determined by best fit) can take away ρ strength.

-In Pb where the background is large, the best fits didn't have a ρ at all, it had to be forced into the fit.

-Overall not satisfactory and hard to conclude

2) Combinatorial background using same charge pairs

$$P(r,\mu) = \frac{\mu^r}{r!}e^{-\mu}$$

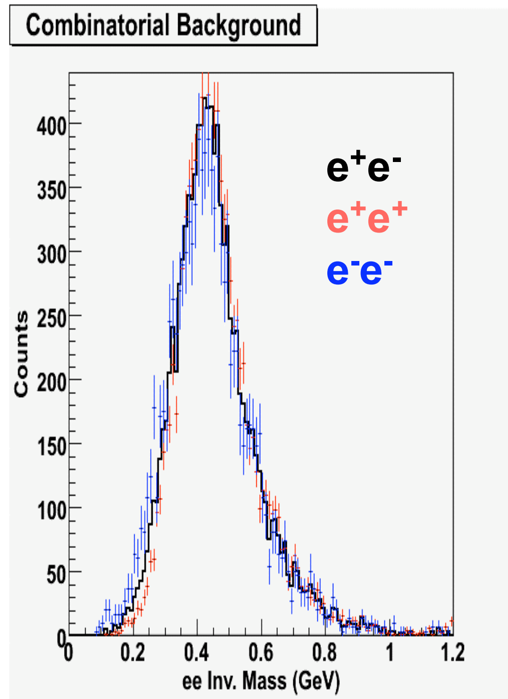
$$P_+ = P(1,\mu_+) = \mu_+ e^{-\mu_+}$$
$$P_- = P(1,\mu_-) = \mu_- e^{-\mu_-}$$

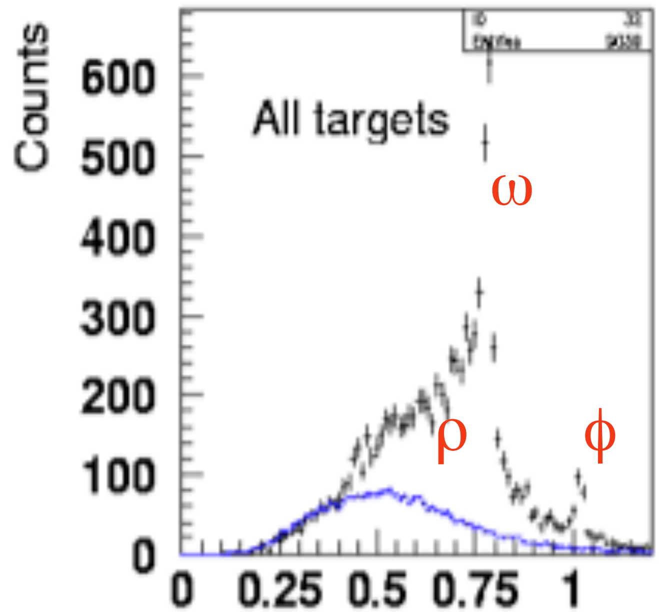
$$P_{++} = P(2,\mu_+) = \tfrac{1}{2}\mu_+^2 e^{-\mu_+}$$
$$P_{--} = P(2,\mu_-) = \tfrac{1}{2}\mu_-^2 e^{-\mu_-}$$
$$P_{+-} = P_+ P_-$$

$$P_{++} = \tfrac{1}{2}\mu_+^2 e^{-\mu_+} = \tfrac{1}{2}\mu_+ e^{-\mu_+}\mu_+ e^{-\mu_+} e^{\mu_+} = \tfrac{1}{2}P_+^2 e^{\mu_+}$$
$$P_{--} = \tfrac{1}{2}P_-^2 e^{\mu_-}$$

$$\mu \ll 1 \Rightarrow e^{\mu} \to 1$$

$$\boxed{P_{+-} = 2\sqrt{P_{++}P_{--}}}$$

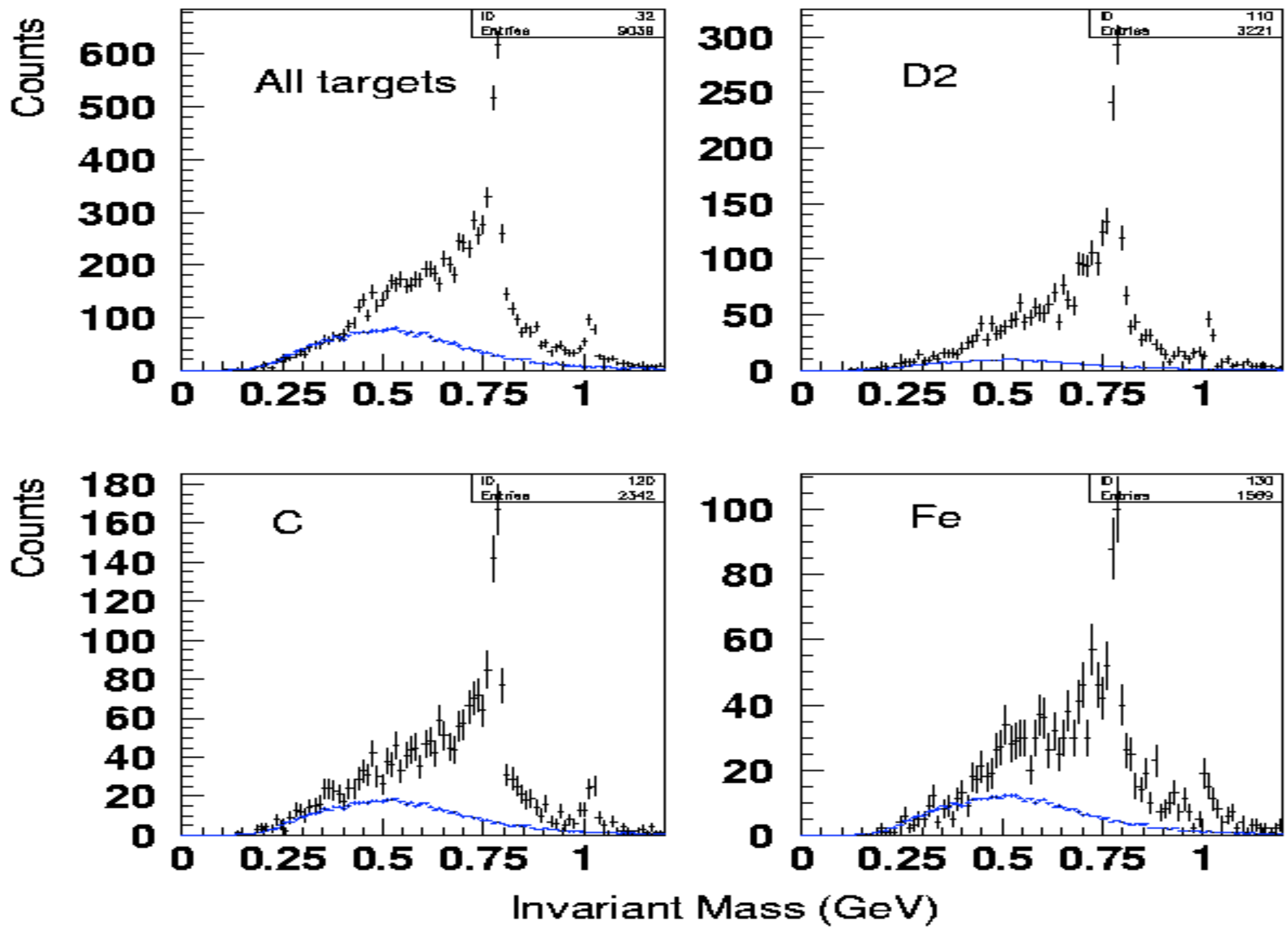




μ+μ– measurement: at CERN-SPS ***IPNO-DR-02.015 (2002***)
π+π– measurement: at CERN-ISR ***(Nucl. Phys. B124 (1977) 1-11).***
e+e- measurement: at RHIC (***arXiv:nucl-ex/0510006 v1 3 Oct 2005***).
Proton Femtoscopy of eA interactions: *ITEP group,* ***CLAS Analysis 2003-103***

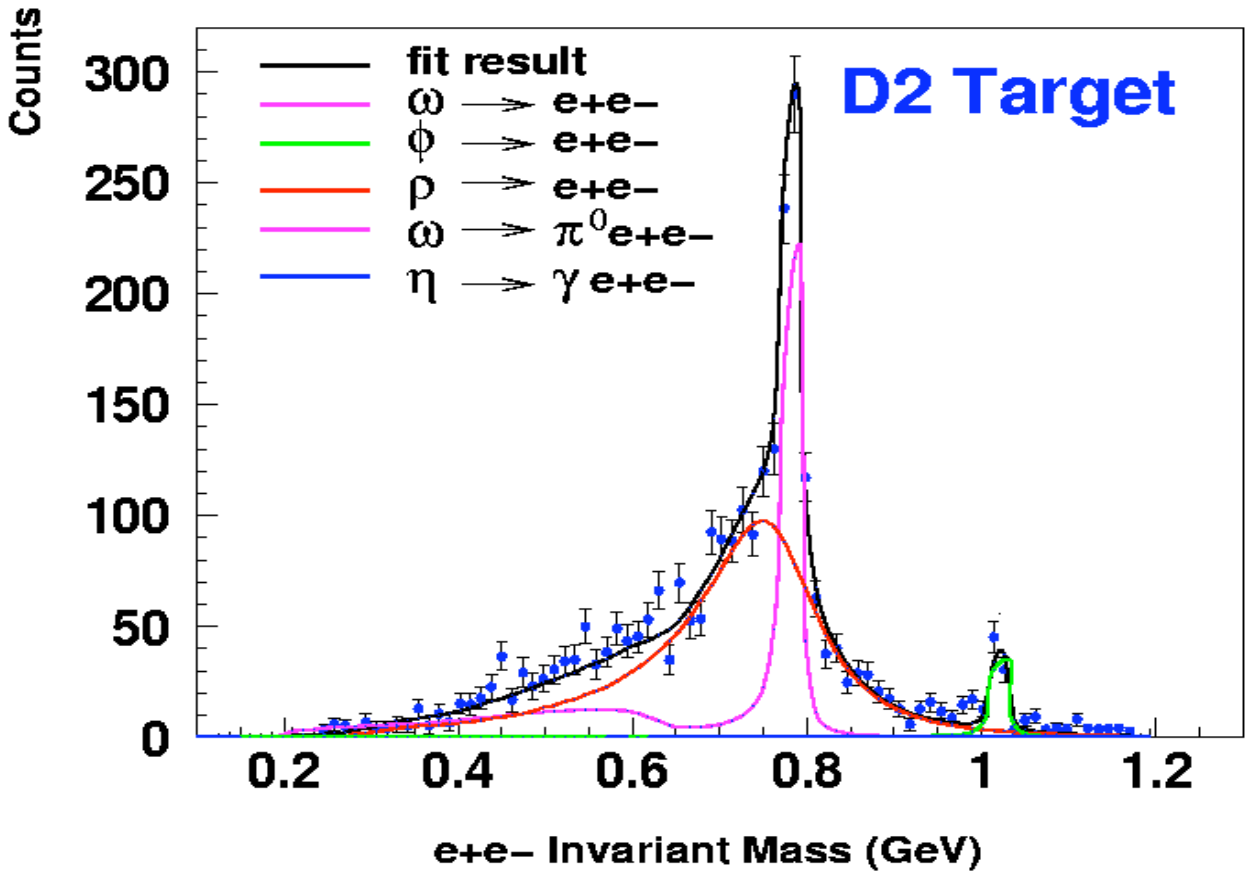
The error on the normalization factor comes from the statistical uncertainties on the N_{++} and N_{--} and is about 4-7%.

Combinatorial BKGD in g7

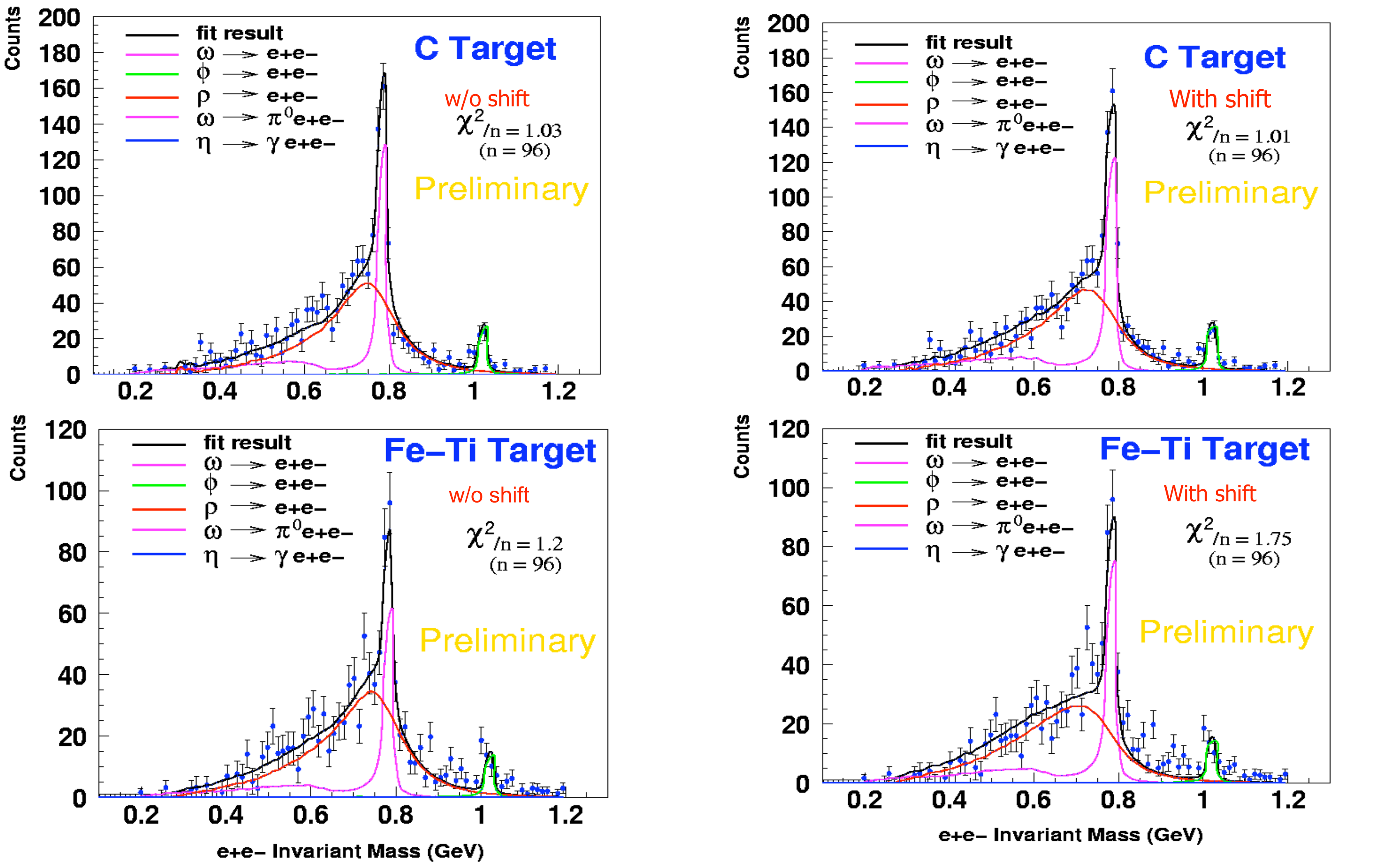


g7a Result : Background subtracted fits

- Model the background using “mixed-events” technique.
- Monte-Carlo distributions generated by Mosel’s BUU model used to fit the data.



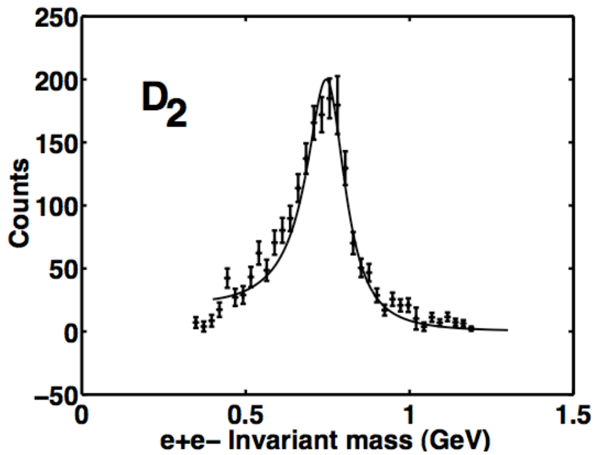
g7a Results: background subtracted

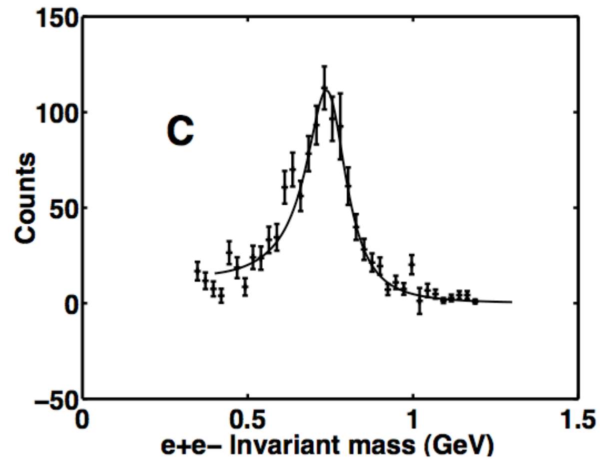


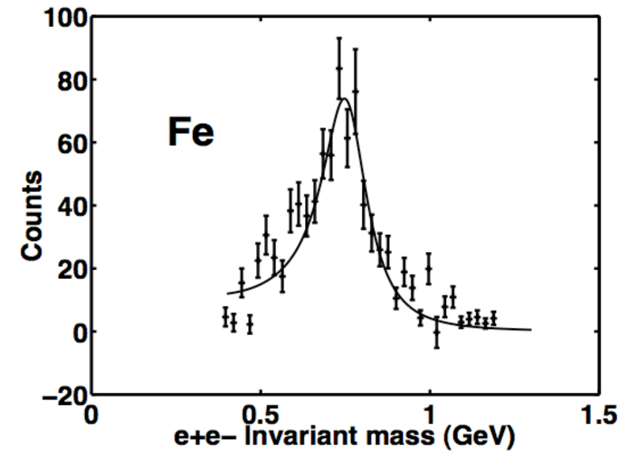
No mass modification $\alpha=0$

Mass modified a la HL with $\alpha \sim 0.16$.

Extracted ρ "spectral functions" from g7a data:

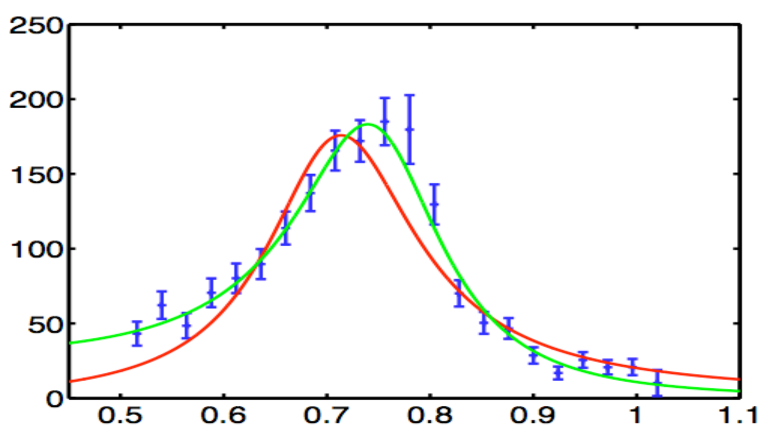


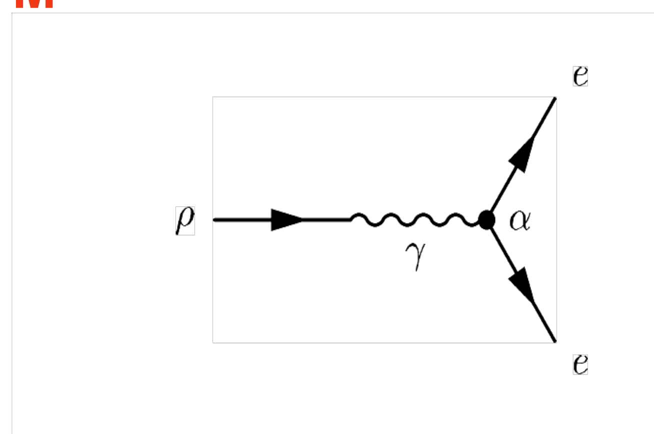




Best fit : Breit-Wigner / M^3

99.7%
Confidence
level





Masses and widths for extracted ρ

Preliminary

Target	Mass (MeV) g7a Data	Width (MeV) g7a Data	Mass (MeV) BUU	Width (MeV) BUU
C	768.5 ± 3.7	176.4 ± 9.5	773.8 ± 0.9	177.6 ± 2.1
Fe	779.0 ± 5.7	217.7 ± 14.5	773.8 ± 5.4	202.5 ± 11.6

Masses are consistent with the PDG value (m = 770.0+/-0.8 MeV), with collisional broadening as predicted by BUU.

In terms of HL parameterization $\boxed{|\alpha| = 0.02 \pm 0.02}$

Summary and Conclusions

- The e+e- pairs from the rare leptonic decay of the light vector mesons are identified with excellent pion rejection factor with CLAS. Clearly seen ω and ϕ signals.
- "Mixed events" technique for the combinatorial background works giving both shape and normalization!
- Correct spectral shape of ρ extracted.
- g7 results are not compatible with large predicted mass shift (α~0.16-0.20) or KEK results (α~0.09)
- g7 results are compatible with no mass shift at all $|\alpha| = 0.02 \pm 0.02$ *and "normal width broadening" as predicted in BUU calculations*
- Need data for lower momentum ρ
- Possible high statistics measurements on H.
- Medium modification studies continue to be a hot topic!

WE NEED TO COMBINE RESULTS FROM DIFFERENT EXPERIMENTS AND HAVE CONSISTENT THEORETICAL MODELS EXPLAINING THE WHOLE PICTURE